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By-Heimer, Ralph T., Ed.

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The preface to this book notes the relationship of its contents to the 1968 conference "to appraise mathematics educators of the present status and future prospects of computer-assisted instruction (CAI) and its implications for the teaching of mathematics." The introduction, "Computers in Mathematics and Other Education," was the keynote address by R. W. Gerard. Part 1 on CAI hardware development contains two papers: "Economically Viable Large-Scale Computer-based Education System" by Donald L. Bitzer and "Characteristics of CAI Configurations from an Author's Viewpoint" by Max Jerman. Three papers presented in reaction to the original papers are by Herbert J. Greenberg, Robert Kalin, and Roger E. Wye. Part 2 on CAI software development also contains two papers, "Development of CAI Curriculum" by Duncan N. Hansen and "Implications of Programing Languages for Mathematics Instruction Using Computers" by Karl L. Zinn, and three reaction papers by Richard V. Andree, William R. Uttal, and J. Stanley McConnell. Part 3 on the developing role of CAI in education includes "Roles and Directions in CAI" by Glenn C. Bacon and "The Computer in Education" by Carroll V. Newsom. Included also are a conference summary by Harold E. Mitzel and lists of invited participants and observers. (JS)

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COMPUTER-ASSISTED INSTRUCTION AND THE TEACHING OF MATHEMATICS

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Proceedings of a
NATIONAL CONFERENCE ON
COMPUTER-ASSISTED INSTRUCTION
conducted at

The Pennsylvania State University
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September 24-26, 1968

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PREFACE

One of the most significant events of the 20th Century—if not in the history of all mankind—has been the development of the electronic digital computer. The impact of the computer on the worlds of science and business is now legion; not so well-known, however, is the fact that it is already affecting the educational enterprise in significant ways—especially in terms of its possibilities for mediating instruction.

The potential of the computer for becoming the ultimate teaching machine did not long go unnoticed by the NCTM Committee on Programed Instruction. Indeed, during 1965 and 1966 representatives of the Committee visited computer-assisted instruction installations at the University of Illinois, The Florida State University, and Stanford University, and as a result of these visits recommended that a conference on computer-assisted instruction be conducted at the earliest possible date in order to apprise mathematics educators of the present status and future prospects of computer-assisted instruction and its implications for the teaching of mathematics.

These early efforts finally came to fruition in September 1968, at The Pennsylvania State University where an invitational Conference having the foregoing objectives was conducted, and it was in the interest of making the results of this Conference available to the widest possible audience that this Report was published.

It is difficult to predict the impact that this publication will have on the mathematics education enterprise, but one thing is certain: it is an up-to-date compendium of thoughts on computer-assisted instruction as expressed by a collection of the most experienced and knowledgeable people to be found.

It is hoped, therefore, that the reader will find this Report to be a suitable entrée into the world of computer-assisted instruction and its significance for the teaching of mathematics.

RALPH T. HEIMER
Editor
Conference Director

ACKNOWLEDGEMENTS

The Conference reported herein was sponsored by The National Council of Teachers of Mathematics and was made possible by financial support from the International Business Machines Corporation and The National Science Foundation. The people who contributed to the planning or conduct of the Conference are numerous, but the following deserve to be cited because their contributions were especially noteworthy: Mr. William Chinn, Dr. Brewster Gere, Dr. Robert Kalin and Mrs. Persis Redgrave, without whose efforts the Conference would never have become a reality; Dr. Donovan Johnson, Dr. Julius Hlavaty and Mr. James Gates, who provided needed support from the NCTM Central Office; and finally to Mr. John Beatty, who served as Conference Coordinator, Mrs. Linda Decker, who handled the secretarial matters and Mrs. Paul Bell, who assisted with the editorial work involved in preparing the Conference Report.

Invited Participants

Richard V. Andree
Leo Arnold
Glenn C. Bacon
Richard H. Balomenos
Clarence W. Bennett
Emil J. Berger
Donald L. Bitzer
John Bradford
Jack F. Bradley
William G. Chinn
Judy Edwards
J. Franklin Fitzgerald
Jack Forbes
Arthur Freier
Ralph W. Gerard
Brewster H. Gere
Elizabeth M. Glass
James F. Gray
Herbert J. Greenberg
Duncan N. Hansen
Larry Hatfield
Ralph T. Heimer
Julius H. Hlavaty
Ruth Hoffman
Vernon R. Hood
Harold V. Huneke
Max E. Jerman
Robert Kalin
Helen Kriegsman
D. R. Lichtenberg
Calvin T. Long
J. Stanley McConnell
M. Anysia McGovern
Harold E. Mitzel
Carroll V. Newsom
Robert S. Patterson
Fernand Prevost
Marian Putnam
J. Ralph Rackley
Persis O. Redgrave
Gerald R. Rising
Irene St. Clair
Charles E. Schulz
Betty D. Sweeney
Ross Taylor
William R. Uttal
John Wagner
Edward H. Whitmore
Arthur J. Wiebe
Robert R. Willson
Roger E. Wye
George Zakem
Karl L. Zinn

Keynote Address

COMPUTERS IN MATHEMATICS, AND OTHER EDUCATION

R. W. GERARD
Dean of the Graduate Division
University of California, Irvine

VIP's and fellow conferees; I'm one of those delighted to come to this meeting because it is at Penn State. I've been, I think, to most of the important universities in this country, I could even say in the world; but I have never been to Penn State and this was much too great an opportunity to turn down. I might otherwise have refused because I'm a bit afraid of mathematicians, but not all that much. As we were walking in, one of the men at the front table said, "Well, can you eat a good dinner before delivering the keynote address?" And I was reminded of the visiting lecturer taken home to dinner by the chairman. His wife had gone to great effort to have a superb repast, but he responded to every offered dish with, "No thank you, I can't speak well if I eat." He finally went off with his host. When the chairman returned home, the lady asked how it had gone, and was informed, "Well, he might as well have et."

When I became an instant expert in computer-aided instruction (because I think that the aid is in the learning rather than the instructing, I've run a more or less unsuccessful battle to get this changed to CAL, Computer-Aided Learning, but was double-crossed by some colleagues at UCI, who named one of our executive languages CAL), some five years ago, some of the better-brewed vintages assured me that the things I wanted and was talking about would come, indeed, in a decade or more. Three years ago most of the things I had been talking about, certainly in the way of hardware, were here. Last spring I gave a talk to a large national group of teachers and afterward one of my colleagues, a mathematician incidentally, wrote me a letter—I think it's the only one of the kind I have ever received—and it was in a mood of understanding sorrow. He said, in essence, "Why did you tell people things that are perfectly trite?" I had thought I had exploded a number of educational bombshells and hadn't been sure that I would get out of the room entirely unscathed! Then, in last month's *Datamation* (September 1968) was a series of articles which really debunked CAI. Not so much the one by Karl Zinn, who will speak to us later, but one author, particularly, pointed out that we had been through all this before, had gotten excited about television and audio-visual aids and about programed instruction and teaching machines, and that nothing much has come of them. CAI was going to go down the same drain! My neighbor during dinner was feeding me this dismal line at a great rate and ended, "Don't you agree?" I said, "Listen to my talk!"

Well, in spite of all these blows, I remain a bull on the subject of computer-aided learning or instruction, though you may decide when you've heard me out that I am very much like a certain mental patient. He had improved greatly, was well oriented and behaved well in the hospital and at an appearance before the review board, seemed well enough to be released. Just before acting, one casually said, "What will you do when you're out?" His eyes lit up and he said, "I'll go out and I'll make a slingshot and I'll get some pebbles and I'll break every damn window in this place." They decided he had better stay around awhile. Some months later, everything was still going well and he came up again for review. He answered all questions clearly and properly. One member then slid in the question, "What will you do if we let you out?" "Well, I'll get a job." "Why do you want a job?" "Well, I've got to get some money—I'd like to have a car." "Why do you want a car?" "Well, I'd like to have a girl and take her riding," he said. "Where would you take her?" "Oh, I don't know, out somewhere, and we'd stop." "Then what would you do?" He said, "Well, I'd put my hand on her leg." "Yes, and then?" "Well, then I'd move it up." "And then?" "And then I'd get her garter and make a slingshot and get some pebbles and break every damn window in this place!"

Be that as it may, I'll try and tell it to you "like it is," or at least like I think it is, or, if I may relapse into older English, "as it is." I suggest that the Cassandras to whom I have been referring have missed the point and I'd like to try to give you my reasons for thinking that they have missed the point.

In the first place, all the things that we now look at and wish we had hardware for, even more wish we had software for, perhaps even more wish we could get some acceptance for, are things that a few years ago, when people began to think of CAL, they didn't even wish for. We're talking about a very different kind of thing today, and the revolution of expectations in this field, as indeed in the minds of our colored brethren in this country, have led to a certain impatience—which is a sign, itself, of progress. What we're talking about now in the way of computer-aided learning resources is utterly different from what was being considered five or six years ago. It is a different animal. I think of the city man talking to a farmer—"Why doesn't that cow have horns?" And the reply, "There are lots of reasons why cows don't have horns. Some have been bred so they're born without horns; some lose horns because of disease; often calves are dehorned; but that particular cow doesn't have horns because it's a horse."

Then we often overlook another thing. The reason, I'm sure, that experts in the field told me some of the hardware I wanted was ten years off when it was only three years off, was because each is so acutely aware of the problems he is personally struggling with to get on with the job that he forgets that there are hundreds of others similarly getting on with the job and solving one or another problem. It's only after a while, when all these solutions get together and the machine is assembled, so to speak, that a really new and advanced model emerges. I am, therefore, not too pessimistic about some important developments in the near future.

It is easy to denigrate television and other audio-visual aids, but the blackboard and chalk are audio-visual aids and the book was, of course, the major technological advance of five centuries ago. I suggest that some of the people who wash it out so quickly take a look at some important successes that *have* been achieved with television education. In American Samoa, for example, the whole educational system was built from scratch on a TV network. There not only aren't enough teachers to teach, they couldn't possibly teach enough teachers to teach, within generations; but education got underway with television, which has been used quite effectively in many places.

As far as the teaching machine and the programed text, I do feel a little negative about them, but in a kindly way. I consider this the marsupial stage of programed instruction, rather poor and primitive. Many poorly qualified people moved in fast to exploit the new gadgets. This was easy enough to do and industry poured in materials, often shoddy; and in spite of that, a good deal came out of it. Certainly some of Fred Skinner's findings on teaching mathematics in the eighth and ninth grades, increasing the speed of learning and level of performance with teaching machines, remain as quite remarkable achievements; I haven't heard them challenged.

Television reached a wider audience but with no feedback, like a book. The teaching machine, like the teacher (the original and perhaps the best teaching machine or learning aid) reaches a relatively small number, but with good interaction. The teacher is necessarily occupied with many other chores besides teaching; a figure a few years ago was that only 15 percent of contact time was spent teaching. Further interaction in large groups was rarely very personal; and it was pretty much seat-of-the-pants flying, was pretty completely an art. The master teacher occasionally was marvelous, and most of the "mine run" were really only occasionally adequate.

The computer has the capacity to reach wide groups, but with individually tailored material (I'll come back to that), in an interactive mode, and with the opportunity, nay the need, of specifying pretty clearly what the objectives of an effort are, what the methodological procedures are for attaining it and, finally, how successfully it was done. So that the computer, I think, for the first time gives the possibility of bringing education out of the completely artistic stage into a science built upon an art—which is what most of our sciences have been.

Let me say a word more about relating to the individual. Many people have written, I have, too, some years ago, about how the computer could take account of the level of achievement in the area of concern of the individual student; could take account of the competencies, the abilities of that individual; could pay attention to each individual's unique learning style—whether he learns better visually or by hearing, inductively or deductively, by repetition or by inviting him to take the lead, and so on; could check each frame in a presentation and find out whether its particular job is being done, whether it is successful or missing the boat. Yet it was only in the July report from Dr. Mitzel's group that I, at least, first saw these four things separately tested out in a computer-aided learning situation. So it can be done! After many people said it would be done, finally somebody has done it. A great deal more doing is required, but it's on the way.

The computer has another very important attribute which I will illustrate by another experience. A year or so ago I was visiting the Oakleaf School in Pittsburgh where Bob Glaser is developing instructional research and materials for the lower grades. As I saw what was going on, I said, "You're really doing essentially what a computer will be able to do." He said, "Yes, we're getting ready to bring the computer in." I pursued the matter, "Isn't it interesting that this kind of individualizing in following the performance of a child, and giving him future work in terms of his actual performance, could have been done without a computer, but that nobody got around to doing it until the computer revealed the possibility?" He said, "You ought to know better than that after your long association with education in Chicago. A generation ago the Winnetka Schools were doing just this kind of individualizing." "Right; I remember hearing of the great work being done there, although I never knew in detail what it was." But it disappeared, and I think I put my finger on the real crux of the problem: this could be done in one school by a devoted leader and group of teachers; but it couldn't be exported, and it wasn't permanent even where originated when the particular master group dissolved. For one reason or another, it was gone. The same approach to engineering the educational processes and materials is now being used at SWRL, the Southwest Regional Educational Laboratory in Los Angeles, one of the Office of Education laboratories. SWRL is also directing attention to the lower level grades, to teaching communication skills, reckoning skills, conceptualization, and some artistic awareness by tested teaching materials soon to be put on computer.

As an example of the difficulty of carrying the fire without some kind of formalization, I give you the magnificent Biological Science Course developed at the University of Chicago for undergraduate biology teaching. It was a beautifully planned and organized course; it was given by enthusiastic lecturers; there were exciting discussion sections; and it achieved such a reputation that the city of Chicago asked to have it given in the junior colleges. We formed traveling teams, like tennis players, and visited a number of the junior colleges and used the same films and texts; the same lecturers gave presumably the same lectures, but what resulted was a very different course. The atmosphere wasn't there and the teachers who had to carry on with the students didn't have what seemed required to make it go. Had the whole course been an automated package, I think it might have gone; and most of it could now be done that way, even some of the give and take of the discussion sections. I learned only today of a consortium, spearheaded by Dr. Mitzel's group, and involving the State Department of Education and the school systems of Philadelphia and Pittsburgh, which is developing a ninth grade mathematics CAL program this year, with several dozen on-line terminals operating in classrooms of the two cities connected to a computer on this campus.

A last reason I will give for feeling bullish about CAI is that the very troubles it is confronting are omens of important advances. When more complex behaviors with more richly integrated systems come into demand, human knowledge must be pushed in areas that have not yet been worked out but now present a challenge to *be* worked out. Happily the computer, and the kind of thinking that goes with it, gives at least the possibility of effective attacks on these areas, which have been rather recalcitrant to analysis in the past. An example is the real analysis of grammar and the equivalence of meaning in different sentence structures—the kind of thing Chomsky has been beating his head against. This becomes a real problem in interactive computer-aided instruction; I'm sure it is going to be worked out—whether in years or decades, I will not attempt to predict. Pattern recognition, which most of you are familiar with, is like a problem; there is much advance in this. Other problems are: the input-output system and coding within the system; heuristics and learning by computers and the need to improve the inputting of information into the machine; and the capacity of machines to self-program along heuristic lines.

This may sound like completely wild science fiction, but let me divert a little into a field in which I will claim some expertise—the nervous system and how it got that way. All such problems were solved in the course of evolution of the nervous system, primarily under the pressure of the environment. The hardware, if I may call neurons and their connections hardware (they are very soft, but the equivalent of tubes and transistors and circuitry), developed first from very shoddy units, say equivalent to the vacuum tube, through the transistor and more recent solid-state devices. Computer memory banks can now be packaged photographically with billions of bits on a square inch of flat surface, say 0.01 inch thick. There are some 10 billion neurons in the brain with an average diameter of the order of, say, 25 microns; and this organ can store trillions of bits in a lifetime. Storage is certainly not a simple spatial matter, as in computer memories, but the packing and retrieval of information is more remarkable. This is not solid state physics but solid state biology, or rather, liquid state biology which evolved, so to speak, under the pressure of environmental demands.

First the units improved, then the circuitry. Such things as negative feedback, which excited engineers a few decades ago, and cybernetics "discovered," were well established in the nervous system long before man existed. Circuits exist all through the nervous system which cut down excessive input volume by a negative feedback, which blocks off impulses on the way up the neuraxis or even right at the receptor itself; and similar feedback loops operate on internal impulse traffic and on output. Then there is the circuitry known as lateral inhibition. In the nervous system, activity of one unit can cut down activity of nearby ones. This is clearly seen in the retina, where shining light on one group of receptors inhibits the response of adjacent ones. The action is reciprocal; so that at the edge between brightly illuminated and dimly illuminated areas, the differences in discharge rates of receptors are greater than between those in the main portions of the bright and the dim areas—those on the bright side of the edge are but little inhibited from the dim direction, while their fellows away from the edge are inhibited from all directions; and the reverse situation exists on the dim side; so right at the edge there is a great exaggeration of the light and dark contrast as sent to the brain. There are other mechanisms of that kind, and the coding within the nervous system is rapidly being unraveled—which patterns of messages give what information (of intensity, of quality, of pattern, of time differences, of movement and muscle position, and so on and so on) to the brain, and so to awareness.

The next, and perhaps the most important, advance in the case of the nervous system was simply more of the same, an increase in numbers. It used to bother me greatly that simply more of the same neurons could permit so much richer capacities. There is a vast difference between what a frog can sense and do and understand, and what a dog or a rabbit can, what his behavioral capacities are; and a still greater difference when you go on to man, when the entire richness of a conceptual world flourishes to a degree that none of our fellow animals can approach; and there seems little question that this is due to the great ballooning of our cerebrum, the vast increase in the number of units. The kinds of units, the kinds of connections, the circuitry, are essentially alike throughout the vertebrates; there are just more of them in mammals and especially in man.

This piling up of more and more central processors, so to speak, followed the creation of more sensitive, richer, more perceptive input devices: sense organs which gave us information about the world at a distance from the body, which we call the distance receptors—smell first, then hearing and vision. This information about predators or prey at some distance obviously has survival value, and receptors evolved steadily. As smell came into being, the beginning of the cerebral hemisphere appeared in the smell region of the top of the brain, then hearing and seeing brought in a great traffic of information and the brain ballooned out with new neurons to handle it. This was true in the lower mammals, of course; what of the larger cerebral mass in man? I was taught in college that man used tools because his large and complex brain, along with hands, enabled him to do so. The teaching today is just the reverse: the use of tools and other environmental inputs led to evolution of the enlarged brain. That experience builds the organism, and particularly the brain, is beyond doubt. (This shorthand statement should not be misunderstood as a Lamarckian position.) And, in closing, I shall consider the potential of computers for further enriching the learning experience by CAL.

These are some reasons why I am not willing to haul down my colors and say that my enthusiasm is premature, that computer-aided instruction is another flash in the pan that will go down the drain with these other efforts from the past. I think CAL is here to stay; that it will have vast consequences never even potentially present with earlier devices; and that perhaps the intense skeptics are a bit like the concertmaster of an orchestra rehearsing with a new conductor. His obvious displeasure finally got on the conductor's nerves. He said, "Don't you like my conducting?" "You are the best conductor we've had." "Well, don't you like my choice of pieces?" "They are very fine indeed!" "Perhaps your violin is giving you trouble?" "No, it's performing perfectly." "Then what *is* the matter? Why are you so unhappy?" "I just don't like music."

Now let us look more positively at computer-aided instruction and especially in relation to mathematics teaching. Its use in what I might call the deductive or algorithmic mode is well established. Here a precise formulation of the situation is possible, from which certain consequences necessarily follow, as in solving equations. Computers have been used this way for years in teaching mathematics, statistics, and science in general; serving as a valuable side tool, like a glorified desk calculator, to make possible an amount of sheer brute calculation which would otherwise have been utterly prohibitive in time and effort. The teacher then can present matters for the student's attention which are intellectually richer and more exciting but otherwise out of reach. At a Joint Computer Conference, a speaker from one of the great universities reported that the statistics course for engineers and scientists had always been a dud. The faculty hated to give it and the students hated to take it. Then he brought in the computer, as a calculator, and the whole course came alive. Instead of most of the time being spent trudging through the desert of operations from intellectual oasis to oasis, this was flown over in an airplane. Of course, when it comes to inverting matrices or doing factor analyses or any number of things that are part of both mathematics and experimentation today, whether in bubble chamber physics or in the psychology of primary mental abilities, it is an enormous relief to leave the drudgery to the computer and let the human get on with the ideas.

It must be particularly meaningful in mathematics to be able to shoot a variable through its domain, or a whole group of variables through their domains, and see the outcomes in a plot on the cathode ray face. The student can get a feel of what happens as an equation is applied in the world, so to speak. Still richer resources are required as the computer serves for out-and-out simulation which, I am told, has helped mathematicians with their theorizing and formulating of concepts, as it has other investigators; and certainly computer-aided instruction can help impart concepts as well as techniques and tools to help gain knowledge and skills. But this perhaps belongs more at the next level.

With some trepidation I shall call this the inductive heuristic approach in contrast to the algorithmic one. Here one doesn't know the answers, can't go logically from *a* to *b* to *c* to *d* but must zero in on it by a series of approximations and generalizations, starting in an artistic or intuitive way but sharpening and clarifying in an iterative trial-and-error fashion.

Let me take an example from a meeting at Chapel Hill a year ago to explore the possibilities of computers in the humanities, at which I had an assignment not unlike this one tonight. Such a gathering was very encouraging, because most humanists simply regard the computer as dehumanizing and unworthy of attention. (Some who take this stand are not very consistent. One of my colleagues, at a "conclave," vehemently denounced the computer as utterly inhuman and depersonalizing. He went on with considerable passion, "I went on a terminal to play a computer game where you mustn't end a word. The computer had me at the end of a common word but I added a letter going into a longer technical one. The computer challenged, "What's your word?" When I gave it, the machine replied, "There is no such word." He closed angrily, "You know that damn machine is still gloating at beating a college professor!")

At that meeting Ellis Page reported his work in developing a program for a computer to grade English themes of college students—surely a task one would expect to be entirely beyond the potential of a computer. He used a heuristic approach and worked out what objective, measurable attributes of a theme served as meaningful indicators of the real attributes one was interested in grading—originality, elegance, whatever you will. He started with

60 items—use of the less usual punctuation marks, average sentence length and its variation, similarly for word length, etc.,—and found that most of them didn't relate to the quality of the theme as judged by expert graders. But half a dozen measures gave good correlations with quality; and when they were used together, the computer graded the themes of a group of college students rather better than did a panel of English professors who taught the composition course. On what basis do I say better? The computer gradings were more consistent with themselves; they tended to match the majority of the graders; there were fewer erratic grades; other English professors, given five sets of grades and asked to pick the one by the computer, were unable to do so.

This is the heuristic approach and I dare say that it might be of great value in helping teach concepts in mathematics, that it might even help define objectively what all good mathematicians are well aware of subjectively, that there are levels of elegance in a mathematical manipulation and solution.

Permit me to make another suggestion along these lines. Children, especially but not uniquely girls, are pretty generally put off mathematics from the start; and by the time young people get to college an equation causes a shutting down of the sensorium. I am convinced this is quite unnecessary. I shall never forget a demonstration by David Page at Woods Hole, not done with the computer but by a master teacher flying by the seat of his pants. He took a group of sixteen kids from the local schools, strangers to him and mostly to each other, and in less than an hour, using the Cuisenaire rods—each a square centimeter cross section and varying even numbers of centimeters in length, each length a different color—he first taught them the idea of a square surface, the notion of the square centimeter as a unit of measure, had them calculating the surface area of different rods, and solving simultaneous equations. He went on with no "props" to give them the notion of functions, and they operated with functions very successfully; there was no question but that they had grasped the principle. All this well within an hour of hard thinking. The nicest part was when the children were done, on the way out they shook hands with their task master and said with real enthusiasm, "Thank you, Dr. Page!" They'd had the best fun they'd had in a long while. These were not selected from the top of the class; it was perfectly clear as you watched them that some were good and some were not very good, but they all managed it. Half of them, I learned later, were from the upper quartile of their classes and the other half were from the two lowest quartiles. Well, these things can be done by an individual master teacher; I am convinced that nearly everything that he did could have been done with a good CAL program, which could reach millions rather than dozens.

Now let us jump ahead to what computer-aided instruction has to offer more generally. It certainly can offer the student an opportunity to proceed individually—in terms of content, in terms of pace, in terms of learning mode. It can offer him up-to-date and rich materials, rarely fully available to most teachers in most schools. It can offer him particularly vivid quality teaching experiences, and therefore learning experiences. It offers the teacher, of course, the opportunity to advance or refresh her knowledge, and particularly it takes off her back the vast amount of scut work that makes teaching much less an art than a policeman-housemaid-drillmaster service. It offers the opportunity in the curriculum of breaking down the monolithic educational units which start and end with the semester or quarter and which everybody has to go through for just that length of time. Material must be added to fill it up or cut off to get into it and different courses multiply for each particular different use. Computer-aided units can be as small or as large as desired. The advantage of small ones is that these can be combined in all sorts of different ways, like building blocks, to shape a particular course to a particular student's need.

I'm much concerned with this right now from quite a different point of view. We have a new medical school at U.C. Irvine, newly moved from Los Angeles; now we are faced with the problem of deciding what our future stance should be in the whole health area. There is a fantastic number of occupations in the health area—not only doctors and dentists and nurses and pharmacists and veterinarians and public health officials and the like—but, at a less advanced level, there are some 200-odd formally recognized occupations, many of them licensed: X-ray technicians, physiotherapists, inhalation therapists, medical record keepers, audiologists, optometrists, their name is legion. Well, which of these should a university be concerned with; what kinds of interrelations could a university establish with other related educational institutions in the community to educate in this area; is it necessary to have separate courses for each group or is it possible that one could really have a sufficiently clear "job analysis" of what people must do to deliver health care to the people, and then find out what kind of skills and knowledge a person needs in order to do this job or that job or the other? I am sure that in few cases will the educational needs and service activities correspond with the current professional or occupational terms. Then could one not think of having an education which starts like the trunk of a tree, all getting off the ground together, with branching off at different levels or stopping at different heights? The girl who is going to be a registered nurse certainly has to know there is a heart and liver and a bit about how they function, which also the internist who is going to be the top pin in a health delivery team must know; so maybe all could learn certain things together. But all cannot be put in one huge class because of different learning rates, backgrounds, and other variables—aside from sheer numbers. Some small units of educational material could be used for all, some only for smaller groups. So much in the way of curricular gain.

In institutional gain, we hear a good deal about networks. I mentioned the consortium centered on this campus. EDUCOM, the Interuniversity Communication Council, is trying to bring together universities and colleges of the country to form an interacting governing body and has just got underway a considerable program (EIN—Educational Information Network) for developing a network of exchanging computer programs and computer terminal use. The Pentagon's ARPA, Advanced Research Projects Agency, has a more sophisticated network for a limited number of participants. These activities will grow rapidly, so that soon what is done in any one place can be applied in any other. As I like to say, it is no longer necessary to move bodies for information to flow between the teacher and the student, even on a two-way basis; the information itself can now be moved over long distances in an interactive mode. This makes a great deal possible, so that I do really think of a university without walls, a school without walls, with individual students connected from homes or work places with a central CAL system. I will hastily agree that some things which happen to people when they are together cannot be duplicated at a distance and are very necessary; but most of these are independent of the process of intellectual growth.

The educational establishment, the whole system, is also due for great changes. I think the rather severe artificial boundary between being in school and being in life, which so many of the young people in the world seem to be resenting violently at the moment, is likely to resolve by appropriate evolutionary or minor revolutionary changes made possible by these newer technologies. If the educational establishment remains rigidly conservative, as establishments tend to do, change probably will take place outside of the establishment, and bypass it. Parenthetically, I take a dim view of the extreme young people, who are both impatient and ignorant, as most revolutionaries are who want to change everything immediately and are likely to end by destroying the good with the bad. A much better way of reforming the educational system is by exploiting these newer technologies. A wonderful cartoon in a recent *New Yorker* showed a rather prissy secretary handing the phone to her boss, busy with papers at his desk, and in the background the chimneys of the big factory he runs, "It's your son. He wants you to drop what you're doing and change the world."

A point in closing. Computers, and computer-aided learning, as an important aspect of their use, are likely to make major changes in society, and in man himself. I alluded to this earlier: if the richer impingement from the environment on organisms able to receive richer stimuli has led to the growth of the brain, I strongly suspect that further enrichment of the environmental input may continue to accelerate that process. The real problem in society is the progressive complexity of the problems with which we have to deal because we're a more advanced system, a more advanced social organism, or epiorganism, as I like to call it; and we do have automation coming in and taking over the more menial jobs so that humans will have to be qualified to do the less menial ones. I think we haven't a chance of getting this done without CAI help. I doubt that anyone has remotely developed his inborn potentialities during his own life experience, formal education or otherwise. I would guess maybe only a third of the potential has been realized. I can't justify this figure but am pretty sure it's not wildly off, and some others agree with me. So one can right now upgrade the effective performance of men as they now are, but I foresee a change in man himself that is an evolutionary one over generations as a consequence of an input of a richer, more effectively structured learning experience. Just as the distance receptors and tools turned an ape into a superape, this richer input may well some day turn man into a superman.

PART I

CAI HARDWARE DEVELOPMENT

ECONOMICALLY VIABLE LARGE-SCALE COMPUTER-BASED SYSTEM

D. L. BITZER
Computer-based Education Research Laboratory, University of Illinois

In my talk this morning I am going to discuss the design of an economically viable large-scale computer-based education system. In computer-based education (CBE), hardware and software are very closely coupled. Once a teaching strategy is determined, limitations are placed on the system hardware. Because of this dependence, the Computer-based Education Research Laboratory at the University of Illinois spends 50 percent of its time in what I refer to as the *science* of computer-based education, and the other 50 percent of its time on the *engineering* of computer-based education. In science the emphasis is usually on developing understanding, independent of cost, but in engineering, costs become a central factor. Before computer-based education can make an important dent in our educational load, it must become economical. As one would expect, we needed to develop the science in CBE before we could do the engineering. Today I will speak mostly about the engineering aspects and discuss new devices necessary to make computer-based education an economically viable educational tool. Later, I will demonstrate one of these new devices, the plasma display panel, which promises to make remote computer graphics inexpensive.

Some of the broad aspects we must consider are: what we are going to teach, whom we are going to teach, what type of teaching strategy we are going to use (tutorial, inquiry, or drill and practice), and where we are going to teach (school room, dormitory, home). In addition, the cost should be comparable to traditional classroom cost (27¢ per hour at primary school level). Technology is developing rapidly. If we plan carefully, what costs $10 per terminal hour today may be only 25¢ per terminal hour in a few years.

In planning for a computer-based education system, the engineer must convert statements and terms such as drill and practice, inquiry, tutorial, graphic-pictorial, rapid response, answer processing, etc. (descriptive words used in this field), into hard computer science terminology like bits per second, channel capacity, displays with inherent memory, instructions per second, memory size, etc.

Let me describe the science aspect of computer-based education which is a necessary step before the engineer can do this conversion. We needed a data base to determine the computer and terminal requirements for teaching different courses by a variety of teaching rules. To generate this data base, we taught courses for credit in library science, electrical engineering, nursing, algebra, geometry, arithmetic drill, chemistry, biology, and a number of foreign languages. We taught them using drill, tutorial, and inquiry teaching strategies. Presently we teach about 800 student contact hours each week. This week we are teaching French, Latin, geometry, maternity nursing, and psychology. As one course finishes, another will replace it. Although the total number of student contact hours is relatively large, each course usually involved only 100 to 200 student contact hours. It is difficult to do meaningful educational analysis since we do not have a good model for the way a person teaches or learns. However, we do have excellent models representing computers including parameters such as instructions per second, memory size, and cost. All of these parameters can and are measured very accurately with our present system, permitting us to do a fairly accurate system design.

The 70,000 student contact hours correspond to over 70,000,000 buttons pushed by the student, with almost all of these requests recorded for processing. The data used in this talk for the design of a large-scale CBE system is based on these records.

To calculate the computer requirements and cost, we will need to determine the average number of requests per student and the distribution of the computer processing time for these requests. The 70,000,000 button pushes for 70,000 student hours indicates that each student on the average pushes a button every four seconds. How long does it take the computer to process a student's request? We find, not much to our surprise, that the distribution of requests is shaped roughly like an exponential curve, with the frequency of occurrence being the vertical axis and the processing time being the horizontal axis. Seventy percent of the time, the students are typing in constructed responses; although this occurs frequently, the computer can process these requests in a very small amount of time using few computer instructions. This is illustrated on the curve where small processing time corresponds to a large frequency of occurrence. Once the student completes a constructed response, and asks the computer to judge it, it is processed in very sophisticated ways. Algorithms are programed in the computer for determining the correctness of a student's response. For example, if the student is constructing a geometric figure, the correctness of the figure is determined independent of its size, orientation, or location on the screen. If the response is alpha-numeric, such as a sentence, it is typically judged not only for absolute correctness, but for misspelled words, for completeness, and for other special properties of the answer. In some cases the student is informed that his answers are correct but one may not be sufficiently different from another. This processing of answers, which requires a large number of computer instructions, occurs only about five percent of the time.

The average processing time needed to fulfill a student's request has been determined from this data as 20 milliseconds. Our present computer (CDC 1604) is capable of processing 50,000 instructions per second. Therefore, 20 milliseconds processing time corresponds to an average of 1000 instructions to process a student request. Knowing the average number of instructions needed to process a request permits us to calculate the processing time for other computers. We are designing our new system to provide twice as many instructions (2000 instructions per request on the average). If we consider a modern computer presently available, it is possible to compute at a rate of four to eight million instructions per second. Using the lower rate of four million instructions per second, we find that 2000 instructions requires 500 microseconds to process. We want to design the system so that the probability of a student waiting a tenth of a second or longer is very low. We can assure excellent response time by using 1 millisecond instead of 500 microseconds as the average processing time on a fully loaded system. Much of the remaining time can be used for background batch programing. Since each student makes a request every 4 seconds on the average, and we allow an average of .001 seconds to process the request, a fully loaded system can handle 4000 students simultaneously. On the average, we are performing 500 instructions per second for each student.

In order to service requests at this rate we cannot transfer data from disk units with each request. Instead we allow an average of 500 words per active terminal. This is 200 words more than is presently utilized. These are 50-bit words, which cost approximately 2¢ a bit or $1.00 per word. For the 4000 terminals we will need 2 million words of extended core memory. The main frame of the computer will cost approximately 2 million dollars, the extended core memory 2 million dollars, and other peripheral equipment, excluding the student terminals, an additional 1 million dollars. Large systems are usually paid for over a 5 year period. The 5 million dollar central processing system will cost approximately 1 million dollars a year. If the 4000 terminals in the system are utilized on the average of 8 hours a day for 300 days a year, we have approximately 10 million terminal hours of usage each year. This gives a cost of 10¢ per terminal hour. The remaining computer time is available at no cost. As inexpensive as this seems, the comparable cost for teaching in the classroom at the primary level is about 27¢ per student hour, and we have not yet included communications costs or the expense of sophisticated terminals. If we allow 10¢ per hour for each terminal based on the same usage as the computer, we can spend 5 million dollars for 4000 terminals or $1,250 per terminal. This terminal must have a graphic display with inherent memory, superimposed randomly selected slide images, randomly selected audio response and a keyset input. At the present time, terminals of this type are not available, particularly at $1,250 each.

Innovation was needed to provide a display with inherent memory—one that would, in addition, be transparent to provide slide image superposition and one on which the computer could write and erase point by point without disturbing the neighboring points on the display. A new device which I will demonstrate later, is now under development at the University of Illinois and other laboratories. This device combines the properties of memory, display, and high brightness in a simple structure of potentially inexpensive fabrication. In contrast to the commonly used cathode ray tube display, on which images must continually be regenerated, the plasma display retains its own images and responds directly to the digital signals from the computer. This feature will reduce considerably the cost of communication distribution lines. The plasma display is discussed in detail in published reports. Briefly, it consists of a thin glass panel structure containing a rectangular array of small gas cells (about .015 inches diameter of about 40 cells per inch). Any cell can be selectively ignited (gas discharge) or turned off by proper application of voltages to the orthogonal grid structures without influencing the state of the remaining cells. The plasma panel is transparent, allowing the superposition of optically projected images.

A schematic of a proposed student terminal using the plasma display is shown in Figure 1. The display will be approximately 12 inches square and will contain 512 digitally addressable positions along each axis. A digitally addressable slide selector and projector will allow prestored (static) information to be projected on the rear of the glass panel display. This permits the stored information to be superimposed on the panel which contains the computer-generated (dynamic) information. The projector will contain an easily removable 4-inch-square film plate containing at least 256 color images. Based upon models now being tested, a low-cost image selector with less than 0.2 second random access time is anticipated.

Data arriving from the computer via a telephone line enters the terminal through an input register. As previously stated, data rates to the terminal will be held to 1200 bits per second. Assuming a word length of 20 bits, the terminal could receive data at 60 words per minute, an improved design feature when considering standard TV tariff for communicating. With proper data formats, data rates will be adequate for the applications envisaged. For example, packing three character codes per word will permit a writing rate of 180 characters per second, which is a much faster rate than that of a good reader. In addition, continuous curves requiring only 3 bits to specify the next point can be drawn at rates

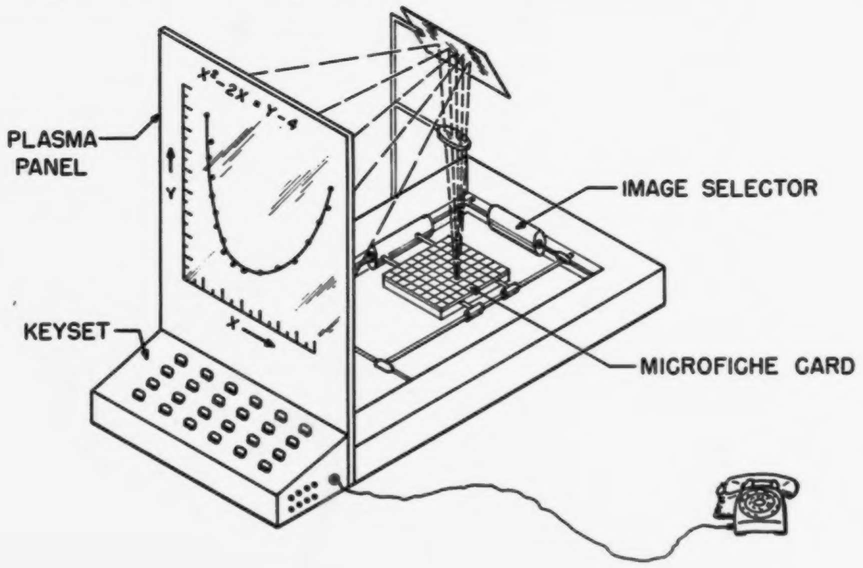

FIG. 1—Schematic drawing of the new student terminal

of 360 points per second. The keyset will provide the student with a means of communicating with the computer.

In the situation where a large number of students are located at considerable distances from the central computer, costs can be lowered drastically by use of a coaxial line instead of numerous phone lines. For example, the cost for a 4.5 MHz TV channel is approximately $35 per month per mile, whereas the corresponding rate for a 3 KHz telephone line is approximately $3.50 per month per mile. Each TV channel can handle at least 1500 terminals on a time-shared basis, each terminal receiving 1200 bits per second. Hence, for an increase in line cost of a factor of 10 over that of a single channel, an increase of a factor of 1500 in channel capacity can be obtained. Data to remote locations will be transmitted by a coaxial line to a central point; from this point local telephone lines rented on a subscriber's service basis would transmit the proper channel to each student terminal. A block diagram of a proposed distribution system to several remote points is shown in Figure 2.

Over 200 cities, and on a more limited scale many schools, already use community antenna television system or closed-circuit TV. Because FM radio had already established itself prior to the spread of television, a frequency gap existed between channels 5 and 6 which is almost 8 channels wide. These existing channels can be used to communicate to over 12,000 home terminals.

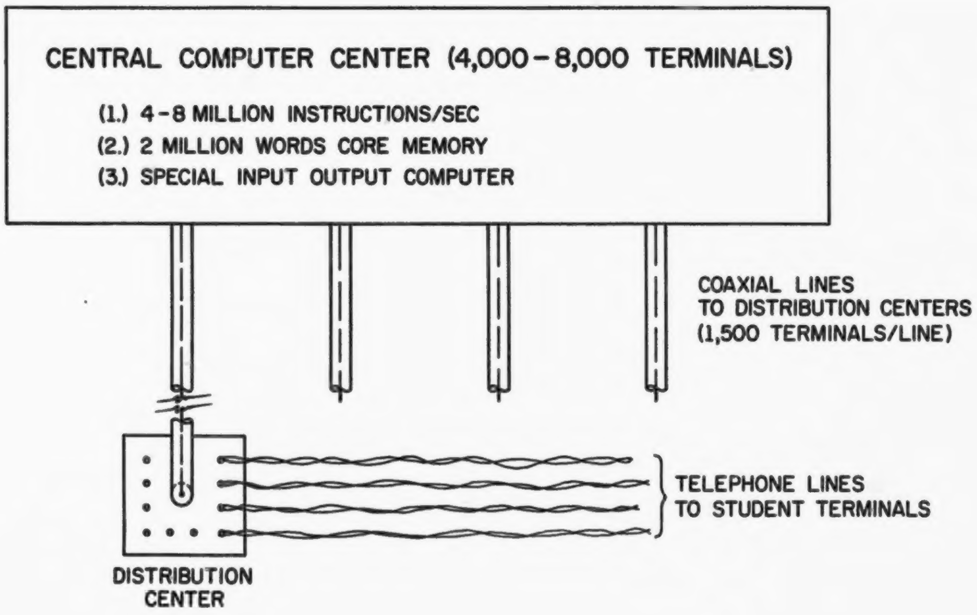
CENTRAL COMPUTER CENTER (4,000-8,000 TERMINALS)
(1.) 4-8 MILLION INSTRUCTIONS/SEC
(2.) 2 MILLION WORDS CORE MEMORY
(3.) SPECIAL INPUT OUTPUT COMPUTER
COAXIAL LINES TO DISTRIBUTION CENTERS (1,500 TERMINALS/LINE)
TELEPHONE LINES TO STUDENT TERMINALS
DISTRIBUTION CENTER

FIG. 2—Schematic drawing of communication distribution system for PLATO IV

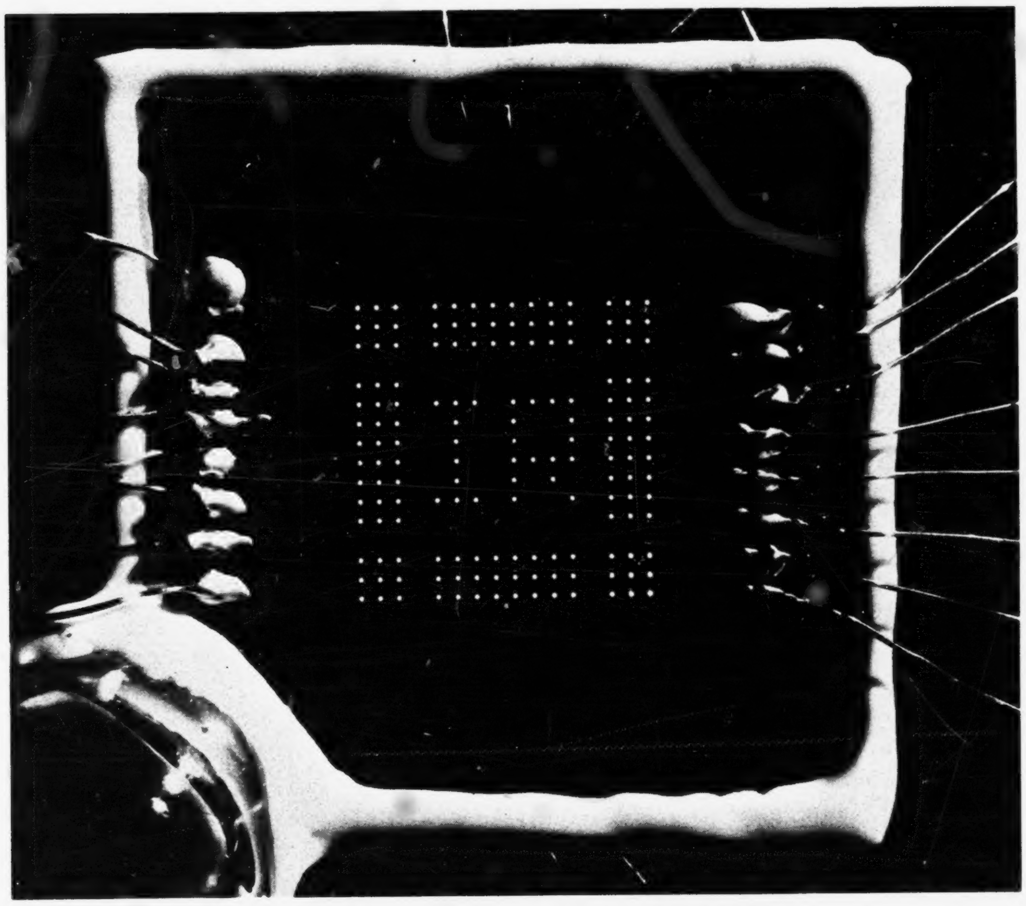

Fig. 3—Small prototype plasma panel

Let me return now to the new plasma display panel. I have a small model on the table which can be viewed on closed-circuit TV in the front of the hall. (See Fig. 3.) I will selectively write and erase different points on the panel and demonstrate its property of inherent memory.

CHARACTERISTICS OF CAI CONFIGURATIONS FROM AN AUTHOR'S VIEWPOINT

MAX E. JERMAN
Research Associate, Institute for Mathematical Studies in the Social Sciences, Stanford University

Since the first commercial computer began operation in the Census Bureau in 1951 (Macy, 1966), so many developments have followed in such rapid succession that it is difficult to realize that the computer has been with us such a short time.

Some of the most profound developments have been in the application of computer technology to the field of education. It is the expectation of many that the oft-heard theme in education, that of providing individualized instruction for each student, will be realized only after we have learned how to use this new technology. We still have much to learn about many fundamental issues in education, such as individual differences in ability and learning rate. For example, no one pretends to have solved the problems of adjusting the pace and treatment of curriculum in any subject area to the background knowledge or aptitude of any student.

The aim of this paper is to discuss some of the characteristics, capabilities and limitations of existing CAI configurations from the viewpoint of a course author. By *CAI configurations* is meant the system hardware, particularly the terminal hardware or instructional terminal. The systems discussed here are operational ones on which reports have been published or for which curriculum is being developed.

Instructional Systems

Suppes (1966a) described three approaches to CAI, which represent different levels of interaction between student and instructional system. Only two of the three approaches are operational at present.

Drill-and-practice system

The simplest instructional system is a drill-and-practice system. The instruction provided by this approach is supplementary to the regular curriculum taught by the classroom teacher. Each new topic or concept is introduced by the classroom teacher. Students work at the instructional terminals on exercises or review material previously introduced in class. Skills are maintained at a high level and difficult exercises are mastered through daily interaction with an eternally patient and tolerant instructional system.

For the past three years, the Stanford Project has provided a daily drill-and-practice program in elementary mathematics to children in public schools in several states. A daily spelling program was also run in one California school. During the past school year well over 250,000 lessons were completed by approximately 4,000 students enrolled in these two programs: over 3,800 in the mathematics program and the remainder in the spelling program. The programs themselves are described in detail elsewhere [Suppes (1966b), Jerman (1967), Knutson (1967), Fishman, Keller, and Atkinson (1967)].

Tutorial system

A tutorial system is intended to provide as much of the actual instruction as possible. A tutorial system assumes the major burden of instruction rather than play a supplementary role like a drill-and-practice system.

Most of the instructional programs in use in the various computer instructional centers are tutorial in nature. At the instructional level the computer can be programed either to adjust the sequence of presentation of curriculum or to alter the treatment. Of course, the more sophisticated the branching and the more elaborate the instructional method, the more complex the computer hardware required to support such an approach.

Dialogue systems

A true dialogue system is not yet in operation. In this mode, a free exchange of questions and answers takes place between student and machine. Three problems must be resolved before dialogue systems can become workable; (a) recognition of student input, either of spoken words or typed messages; (b) interpretation of student's questions; and (c) programing a computer to compose a meaningful response, once the student's input has been "recognized" and "understood."

Programs are now being developed which will recognize certain spoken words and numbers, while other programs being developed will generate spoken messages to students. Although the problems to be solved are substantial, much effort is being directed toward their solution.

Some Criteria for Evaluating CAI Hardware

Possible criteria which a prospective course author might use in the evaluation of a CAI system are: the subject, the population, simplicity of operation, efficiency of operation, and reliability. These points are ranked by importance in terms of my experience with various programs and hardware systems. No doubt others might include other criteria or rank the topics differently; but, for the purposes of this paper, the following general criteria were chosen as most significant.

Subject matter

This point is so basic that it is often overlooked by those who are considering the preparation of a curriculum for a CAI system. Literally thousands of visitors have come to Stanford over the past three years. Many have ordered recently, or are about to order, a CAI system of their own, or plan to tie into some nearby large system. More often than not they describe the wonders of the new terminals and elaborate on their capabilities. When asked what subject they plan to teach, their answers are at best general descriptions of content areas.

Some things simply cannot be done with certain machines. The most basic questions one should ask are "What is to be taught?" and "Is it possible to do what the writer desires on a given terminal?" These questions are especially important for the author languages written for the various systems. Some subject areas, such as geometry, chemistry or foreign language, require special graphics or characters. The graphics or characters need to be displayed in a particular format to be meaningful. It would be difficult to prepare a program in geometry for a CAI system which had no graphic capabilities.

The student population

The question of *who* is to be taught ranks nearly equal in importance with the question of *what* is to be taught. Teaching reading or mathematics to first graders requires a more sophisticated instructional system than teaching the same subjects to students at the secondary level. For example, one cannot assume that entering first graders can read or write; therefore, instructions must be verbal or graphic. The response mode must be simple to operate, one that does not require knowledge of any alphanumeric character set. Displays or other graphics may be necessary to establish basic associations for younger children. Older students, on the other hand, can read the necessary instructional material and respond by using a standard keyboard or some other means.

Along with age, the student's background is also an important factor. Students who are used to an axiomatic approach to mathematics can handle very sophisticated concepts on less sophisticated student terminals, such as teletype machines.

Simplicity of operation

A terminal that is easy for a student to operate relieves the course author of the additional burden of programing instructions to handle special cases of exercises.

The program should be written in a way that does not require the student to respond by performing a complex chain of actions. That is, operating the terminal itself should be easy for the student.

For the course author, simplicity of operation includes the ease of displaying special characters or graphics, using upper case characters, or labeling and identifying parts of a visual display.

Efficiency of operation

The efficiency of a system can have a considerable effect on a course author. Here the author language is often a key factor. If the language used by a specific CAI system makes it difficult to present a course as the author would like, then perhaps another system should be considered or another language made available.

Efficiency also includes the system response time. For example, at Stanford we have found that young children require a system response time of less than 2 seconds. If they respond by pressing a key or touching a light pen to the face of a CRT, and the system fails to provide some kind of feedback in 2 seconds or less, motivation and interest begin to wane. In the drill-and-practice program we aim for a mean response time of ½ second.

The computer which drives the system should be adequate to provide the necessary functions without undue delay. It should be possible for the course author to present information by various means in rapid order. A student working at an instructional terminal should not become conscious of the delays encountered, say, in switching from audio to visual display modes. Instructional systems with well-designed student terminals can be less than satisfactory if student interest lags because time is lost as the system changes from one mode of presentation to another.

Reliability

Anyone who has attempted to run a CAI system on a daily basis in a regular classroom will testify to the importance of having a reliable system. A system which continues to have periodic breakdowns is more detrimental than no system at all. When a system breaks down, carefully planned daily schedules are disrupted. Teachers compensate for these problems for a period of time, but after a certain point, if a remedy for the situation is not apparent, they may begin to feel it is no longer worth the effort.

Reliability applies to other areas as well, for example, easy access to needed films or audio tapes. One of the problems we faced at Stanford several years ago was that of student terminals which destroyed the film they used. We were able to continue only by providing a sufficient quantity of replacement film.

For a course author, reliability is a key factor in the evaluation of his program. For example, an unreliable system prevents analysis of the errors students make. One cannot be sure whether the errors were caused by the system or whether they were honest errors.

Hardware Systems

The subject area and the age level of the target population influence a course author's preferences for terminal hardware more than the decision of whether to use a tutorial or drill-and-practice approach in presenting course content. Any system that is capable of presenting curriculum in a tutorial mode is capable of handling the same material in a drill-and-practice mode. The reverse may not be true, however. Most systems can be used to present curriculum in a tutorial mode. It is a waste of time and money to use a sophisticated system to present simple drill-and-practice lessons when a simpler, less expensive system is capable of doing the same thing. There is no point in driving a Cadillac across campus between classes when bicycling is less bothersome and often less time-consuming. It may be, however, that some sort of motor scooter will serve as the most efficient and least troublesome means of transportation. The point is that there are advantages and disadvantages to every system. The value of a system to a course author is a function of the factors mentioned earlier. There probably is no best system, but only a best system for the task at hand.

Systems' Hardware

The wide variety of hardware in use in various CAI systems reviewed for this paper has led to the classification of systems into types according to the terminal devices used by students in each system. Each system was classified under one of three categories. The categories are: (a) simple systems, (b) intermediate systems, and (c) complex systems.

A simple system

A simple system has as a student terminal a typewriter, teletype machine, or telephone with touch pad. Instructions and lesson material are typed or spoken to the student under computer control. The student responds by using the keyboard or touch pad.

Both tutorial and drill-and-practice programs have been run and are currently being run on simple systems. Uttal (1962) described IBM's early efforts with a simple system for which an electric typewriter (a 1052) was used. At Stanford, simple systems with teletype machines are used in the drill-and-practice mode for students in grades one to eleven and in the tutorial mode with students in grades five to nine.

Most simple systems use either an IBM 1052 typewriter or a Model 33 or 35 teletype. The teletype machine and electric typewriter have many features in common. Both look like typewriters and thus appear familiar to teachers and students. Both machines type questions and student responses on paper, so that the student has a printed record of his work. Both machines use a typewheel or ball-printing mechanism which moves quickly and gives students a feeling of action. Students, especially young children, are fascinated by the rapid motion of the machine as the lessons are printed.

From a course author's point of view, one advantage of a simple system is that content from many subject areas can be presented to students who are able to read and follow directions. Second, a teletype or typewriter terminal is easy for even first-grade children to operate. A third advantage is the reliability of the teletype and typewriter. Both machines work well under heavy use. Though the Model 33 teletype was designed for intermittent use rather than continuous use, it is very reliable even after heavy use for five to seven hours daily.

The major disadvantages of an electric typewriter are the limitations encountered in trying to present various problem formats. For example, line and character positions are fixed and may not be altered. One cannot type on the half line. To type one-half, one must use either 1/2 or $\frac{1}{2}$ (each character on a separate line).

This is not an insurmountable problem, however, since application of the commutative and associative properties permits easy handling of mixed numbers. The fixed line and character position, however, prevents the presentation of geometric figures or special symbols such as $\int_{b}^{a}$. There is also a fixed number of characters one may have on each machine. The typewriter is more restrictive here since more of its characters are fixed and cannot be changed. This becomes a problem when two different curriculum groups, that both need special characters, try to program material for the same terminals.

Another restriction imposed by the typewriter is that once a line has been printed and the next line started, one cannot return to the line above.

For example, to simplify the expression

$$\frac{x^3-y^3}{x-y}$$

one cannot proceed as follows:

$$\frac{x^3-y^3}{x-y}=\frac{(x-y)(\_\_+\_\_+\_\_)}{x-y}$$

because once the denominator is printed it is impossible to reposition the typewheel at the blanks in the numerator. The above restrictions apply to a teletype as well.

This is not to say that it is impossible to do problems of this sort on a simple system. It is the author's task to devise ways of accomplishing tasks like these that are easy for the student to use. One way to approach this task is that used by the Stanford logic program in which the student is required to input only the line numbers of the premises or statements to be operated upon and an abbreviation of the rule that applies. The program then evaluates the student's input. If the rule is correctly applied, the program types the resulting statement. An example of this approach is shown in Figure 1. Figure 2 shows the same approach used in a

```
DERIVE:  2+3=5 & A=3
P             (1)   A=1+(1+1) & 3+2=1+(1+3)
1LC           (2)   A=1+(1+1)
2ID2.1        (3)   A=1+2
3CA1          (4)   A=2+1
4ID3.1        (5)   A=3
R1RC          (6)   3+2=1+(1+3)
6CA1          (7)   2+3=1+(1+3)
7CA3          (8)   2+3=1+(3+1)
8ID4.1        (9)   2+3=1+4
9CA2          (10)  2+3=4+1
10ID5.1       (11)  2+3=5
5.11FC        (12)  A=3 & 2+3=5
12CC                      THE NUMBER OF THE OCCURRENCE IS
                            REQUIRED
12CC1         (13)  2+3=5 & A=3
CORRECT.
```

FIG. 1.—Sample problem from the logic program

problem-solving program. The set of rules used in the logic/algebra program last year are shown in Figures 3 and 4.

Some electric typewriters require an EOB key to be pressed indicating the end of a student's response. Until this key is pressed the system cannot regain control of the terminal to give a student help or sign him off. Also, hitting an EOB key produces an immediate carriage return and line feed which makes it impossible to format and work through problems in mathematics in anything but a multiple-choice or completion-type format. Teletype terminals have not had this restriction. The immediate carriage return and line feed following an EOB in COURSEWRITER II prevents problems of the form:

29 in. = __ ft. and __ in.

because once the student types "2 EOB" the carriage returns to the left margin and the paper moves up one line. These restrictions are being studied now with the aim of eliminating them. When this is achieved the simple system which uses 1052 typewriters will be much more useful in many more subject areas, particularly mathematics.

Simple systems may also be used in conjunction with other materials students may bring with them to the terminal. For example, the science team of the INDICOM project of Waterford Township School District in Pontiac, Michigan plans to provide each student with a box of numbered rock samples (INDICOM, 1968). The program instructs a student to select a certain numbered sample.

```
601.103

COMMITTEE MEMBERS BOUGHT 3 JARS OF CANDY
WITH 14 OUNCES IN EACH JAR, AND 2 BOXES OF CANDY
WITH 27 OUNCES IN EACH BOX. THEY PUT THE CANDY
INTO BAGS THAT CONTAINED 4 OUNCES EACH.
HOW MANY BAGS OF CANDY DID THEY FILL . . .
G              (1)  3
G              (2)  14
G              (3)  2
G              (4)  27
G              (5)  4
1.2M           (6)  42
3.4M           (7)  54
6.7A           (8)  96
8.5Q           (9)  24
9X
CORRECT.
```

```
601.104

THIS IS THE LAST WORD PROBLEM

3 CLASSES OF 32 PUPILS EACH, 1 CLASS OF 34 PUPILS,
4 TEACHERS, AND 7 PARENTS TOOK A TRIP ON 3 BUSES.
EACH BUS TOOK THE SAME NUMBER OF RIDERS.
HOW MANY RIDERS WERE ON EACH BUS . . .
G              (1)  3
G              (2)  32
G              (3)  1
G              (4)  34
G              (5)  4
G              (6)  7
1.2M           (7)  96
4.5A           (8)  38
4.7A           (9)  130
6.9A           (10) 137
5.10A          (11) 141
11.1Q          (12) 47
12X
CORRECT.
```

FIG. 2.—Sample problem from the problem-solving program

It coaches him through a series of tests for hardness, etc., leading toward identification of the sample. Fonkalsrud et al. (1967) described the use of a simple system using typewriter terminals in a program for medical students. Students were given partial information via the instructional terminal, then directed to request laboratory studies, various additional tests or x-ray slides to aid in establishing a correct diagnosis. Rigney (1966) reported the re-

FC—Form a Conjunction

P	(1)	R	
P	(2)	S	
1.2 FC	(3)	R & S	

LC—Left Conjunct

P	(1)	R & S	(conjunction)
1 LC	(2)	R	

RC—Right Conjunct

P	(1)	R & S	(conjunction)
1 RC	(2)	S	

CC—Commute Conjunction

P	(1)	R & S	(conjunction)
1 CC1	(2)	S & R	

AA—Affirm the Antecedent

P	(1)	$R \rightarrow S$	(conditional)
P	(2)	R	(affirms antecedent)
1.2 AA	(3)	S	

DC—Deny the Consequent

P	(1)	$R \rightarrow S$	(conditional)
P	(2)	$\neg S$	(denies consequent)
1.2 DC	(3)	$\neg R$	

DN—Double Negation

P	(1)	$\neg\neg S$	('$\neg\neg$' is dominant)
1 DN	(2)	S	
	or		
P	(1)	S	('$\neg\neg$' is not dominant)
1 DN	(2)	$\neg\neg S$	

CD—Commute Disjunction

P	(1)	$R \vee S$	(disjunction)
1 CD1	(2)	$S \vee R$	

DD—Deny a Disjunct

P	(1)	$R \vee S$	(disjunction)
P	(2)	$\neg R$	(denies a disjunct)
1.2 DD	(3)	S	

FD—Form a Disjunction

P	(1)	R	
1 FD	(2)	$(R) \vee (S)$*	

* Filled in by Student

HS—Hypothetical Syllogism

P	(1)	$R \rightarrow Q$	(conditional)
P	(2)	$Q \rightarrow S$	(conditional)
1.2 HS	(3)	$R \rightarrow S$	

CP—Conditional Proof

P	(1)	Q	
WP	(2)	R*	
	(3)	S	
2.3 CP	(4)	$R \rightarrow S$	

IP—Indirect Proof

P	(1)	Q	
WP	(2)	R*	
	(3)	S	
	(4)	$\neg S$	
2.3.4 IP	(5)	$\neg R$	

FIG. 3.—Rules for sentential logic

sults of an experiment in which a Navy transceiver was built into a simple instructional system. Under computer control various symptoms were generated and the student was given directed practice in trouble-isolation procedures.

Probably the most popular application of a simple system is that of teaching computer programing. Many schools and universities have participated in systems such as Dartmouth's. Many of these time-shared networks are used for problem solving rather than CAI; hence, they are outside the scope of this paper.

Stanford's dial-a-drill program is an example of the second type of simple system mentioned earlier. The student terminal

ND—Number Definition
ND6 (1) $6=5+1$

D—Replace number by its definition
(1) $5+B=C+5$
1 D5.2 (2) $5+B=C+(4+1)$

ID—Inverse Definition
(1) $4+1=4+1$
1 ID5.2 (2) $4+1=5$

CA—Commute Addition
(1) $A+B=3+4$
1 CA2 (2) $A+B=4+3$

AR—Associate Addition to the Right
(1) $A+B=(4+5)+6$
1 AR3 (2) $A+B=4+(5+6)$

AL—Associate Addition to the Left
(1) $A+B=4+(5+6)$
1 AL2 (2) $A+B=(4+5)+6$

CM—Commute Multiplication
(1) $A\times B=3\times 4$
1 CM2 (2) $A\times B=4\times 3$

ML—Associate Multiplication to the Right
(1) $A\times B=(4\times 5)\times 6$
1 MR3 (2) $A\times B=4\times(5\times 6)$

ML—Associate Multiplication to the Left
(1) $A\times B=4\times(5\times 6)$
1 ML2 (2) $A\times B=(4\times 5)\times 6$

FIG. 4.—Rules for algebra

is a telephone with a 12-key touch pad. Under computer control, messages such as "How much is 2 and 2?" are prepared and played to the student over the telephone. The actual problems given are computer-generated, according to criteria specified by the course author. The level of difficulty of the problems given any student depends on his own performance. The program generates each lesson individually, on-line, as the student works.

The current version of the arithmetic drill program uses an 80-word vocabulary. Words are recorded, converted into 1-0 digit strings, and stored in memory. The words are played from disk memory in rapid succession to form sentences that are easy for even small children to understand.

Intermediate systems

An intermediate system may be (1) a teletype or typewriter with audio, (2) a teletype or typewriter and film projector, or (3) a teletype or typewriter with film display and audio. On command, the audio can provide either prerecorded, taped messages to the student, who receives the messages over a headset or loudspeaker or can play messages using the digitized speech approach. The student responds using the keyboard.

The simplest intermediate system features a teletype or typewriter with audio. The audio component can be either digitized speech, as described above, or prerecorded taped messages played under computer control. The simplest tape device is a standard tape recorder which plays messages in a linear fashion; that is, the tape recorder is started and stopped by computer control.

To maintain a system that uses a standard tape recorder requires a recorder of high quality, one that can be depended upon to stop within a certain interval after the command to stop playing has been given. This approach has been used at Stanford in the Russian language program for entering freshmen. The computer starts the recorder and allows it to play until it hears a beep tone indicating the end of the message. The course author inserts the beep tone at the end of each message when the tape is first made.

An individualized program has a separate tape recorder for each student. This means that the author must prepare a master tape and have duplicate copies made.

There are several different random-access audio devices. One uses a 6-inch wide tape having 128 tracks, and 8 addressable 1- or 2-second segments on each tract. A single 1- or 2-second segment or any number of segments may be played depending on the nature of the program.

The advantages of a random-access device are that messages may be repeated when necessary and such a system permits the variation required by intrinsic programs.

A disadvantage of such a system is in the fixed segment length itself. Since it will always begin to play from the beginning of a segment, the student may experience a delay. That is, when recording, the author may be waiting for a ready light to indicate that the segment has started. It takes a good deal of practice to begin speaking immediately when the light goes on. If one takes a breath or swallows before speaking that amount of time will be lost. The student will hear a click indicating that the tape has started but must wait for a moment or two before anything is said. Those systems which have adjustable segment markers eliminate this delay feature. The author can play back the tape and adjust the segment markers to eliminate any gaps, thereby achieving a much smoother presentation and increasing student motivation.

Another type of intermediate system uses a teletype or typewriter and a film display. Most often the film display is a 35mm. Carousel slide projector or a random access rearview projector. Adding a visual display increases the flexibility of the program itself and of its mode of presentation. Television has also been used as a component of an instructional system (Franceschi and Hansen, 1967). In the case of either film or TV, the preparation of high-quality film or videotape can present a problem to the course author. In addition to production problems, the author must program his course to take advantage of the displays by making them an instructional part of the program rather than a supplement. Simply having a visual display in addition to a teletype or typewriter does not ensure a significant improvement in learning. It is the task of the course author to weave the display into the program so that the student must make use of the information it contains in order to respond correctly.

A third type of intermediate system includes both audio and visual display. This type of system has been in operation at Pennsylvania State University for some time (Mitzel, 1966). Thirty-nine short programs, running from 20 minutes to 4 hours in length, and four programs 20 hours in length have been prepared for use on this system (ENTELEK, 1968). Some of the programs included the use of textual materials in conjunction with work at the CAI terminals.

Longer programs, ranging from a 45-hour course in remedial reading to a 150-hour course in science for junior high school students, have been prepared for use on the Florida State system (Hansen and Dick, 1967). Students in the science program used laboratory equipment and a booklet, and operated a slide projector themselves. Most of the other systems reviewed had all instructional devices under computer control.

The intermediate system offers the course author several advantages over the simple system. Many of the problem format limitations of the simple system are eliminated by having the film display. If the audio and film devices are random access, a full tutorial program can be given. It should be remembered, however, that every additional component added to the system increases the workload of both the system and the course author. The more complex the branching scheme, the greater the load on the central processor and the greater the probability of a slow system-response time.

An intermediate system will probably be somewhat less reliable than a simple system because it has a larger number of terminal devices. Most of the intermediate systems in operation are used with students of junior high school age and older. Few of the programs used on these systems have been remedial in nature. Better students can be expected to take better care of terminal equipment. It has been our experience, however, that even students who are considered trouble makers cause no problems when working at a terminal which is providing a highly motivational program.

One intermediate system that is apparently very reliable and which is being used with young children is the Talking Typewriter developed by Dr. O. K. Moore, at the University of Pittsburgh. Each machine is a self-contained unit—terminals and small computer. Instructional components include a typewriter, a rearview projection screen, and audio speaker, and a microphone that is used to record and play back the student's voice. All of the keys on the typewriter keyboard can be locked except the one for the correct response. A pointer can be positioned on the rearview projector to indicate words or letters to be spoken or typed.

This device has been very effective in teaching beginning reading. It provides several instructional and response modes, making it possible for the course author to prepare a highly adaptive program.

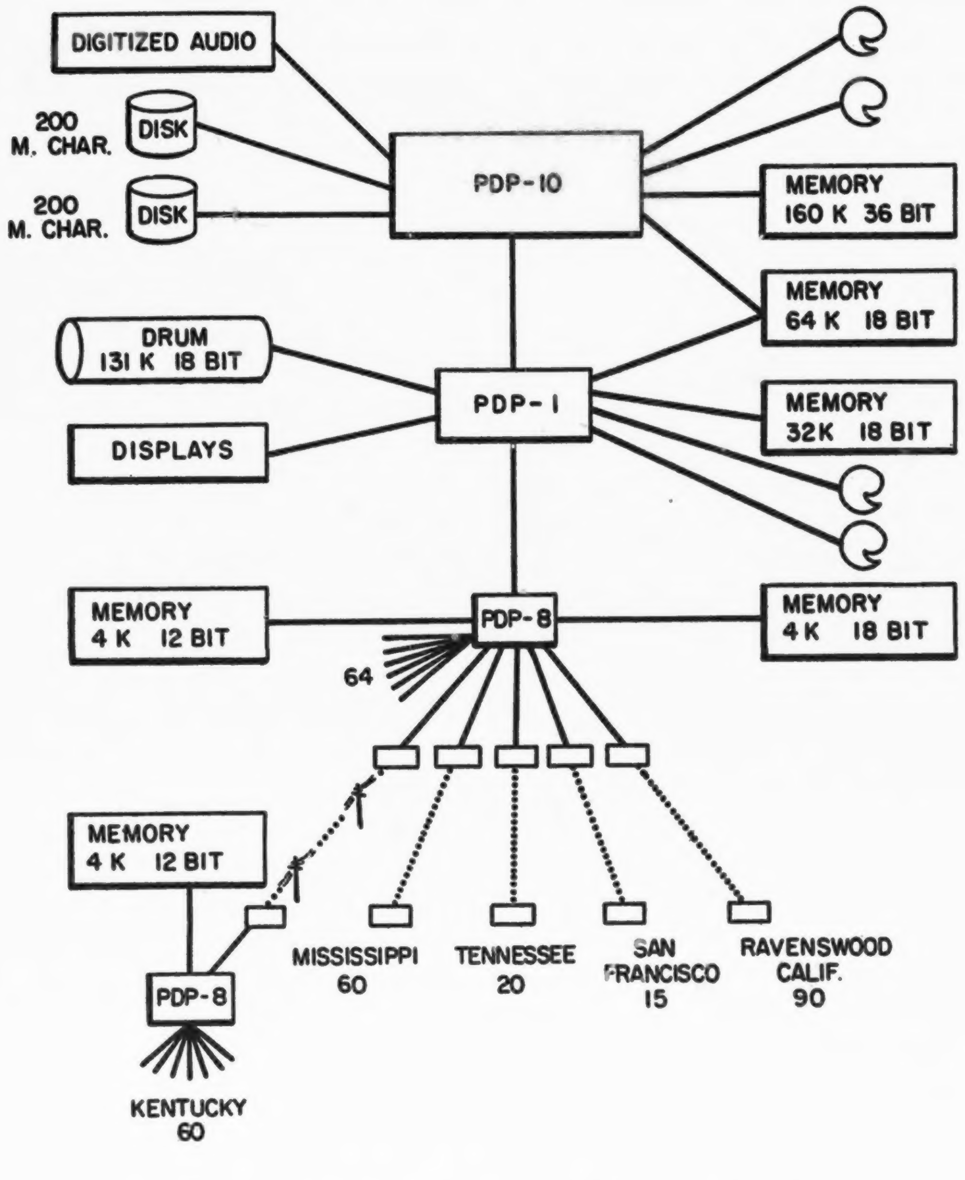
DIGITIZED AUDIO
200 M. CHAR.
DISK
200 M. CHAR.
DISK
PDP-10
MEMORY 160 K 36 BIT
MEMORY 64 K 18 BIT
DRUM 131 K 18 BIT
PDP-1
DISPLAYS
MEMORY 32K 18 BIT
MEMORY 4 K 12 BIT
PDP-8
MEMORY 4 K 18 BIT
64
MEMORY 4 K 12 BIT
PDP-8
KENTUCKY 60
MISSISSIPPI 60
TENNESSEE 20
SAN FRANCISCO 15
RAVENSWOOD CALIF. 90

FIG. 5.—Configuration of the Stanford CAI system

Figure 5 presents a diagram of the current Stanford configuration which supports simple, intermediate, and complex systems. Forty of the 64 lines leading from the central PDP-8 are being used in a reading program for grades one, two, and three, using digitized audio. In Figure 5 the symbol K denotes the number 1024, meaning, for example, that "160K 36-bit" stands for 160×1024 words of memory, each word having 36 bits. The character M denotes million. The capacity of each disk is 200 million characters. Displays denote the 12 cathode-ray tubes (CRT) attached to the system. Digitized audio denotes the component that generates and controls the speech program. The numbers at the bottom of the figure, for example, Mississippi 60, indicate the number of teletype terminals in operation when all the telephone lines are installed. In Figure 5 the word "Memory" indicates core memory while "disk" and "drum" indicate the two other types of memory devices in the system.

Complex systems

A complex system may be (1) a cathode-ray tube (CRT) with keyboard, (2) a CRT with keyboard and audio, (3) a CRT with keyboard, audio and film display, or (4) a CRT with keyboard, audio, film display, and typewriter. A student responds on the keyboard, by touching a light pen to the face of the CRT, or by using a microphone to make voice recordings which can be played back by the course author at a later date.

The first of the complex systems considered is a cathode ray tube (CRT). Machover (1968) identified two major categories of CRT displays, alphanumeric and graphic. Alphanumeric displays are those which display only alphabetic, numeric, and special characters. The characters are usually displayed in predetermined positions like a typewriter. Options include such things as a light pen and cursor. A keyboard is not considered an option, but is a necessary part of the instructional terminal.

Graphic displays can present line drawings, curves, and schematics in addition to alphanumeric characters at random positions. Most low-cost CRT displays (less than $20,000) use a 5 by 7 dot matrix to generate characters and graphics. Some use an 8 by 12 dot array. More expensive CRT displays produce images by vector generation or other means (Theis and Hobbs, 1968).

The CRT has several advantages over a teletype or typewriter. First, it receives and displays messages at a much faster rate—120 to 300 characters per second as compared to 10 to 20 characters per second by a teletype or typewriter. Lessons, therefore, can be presented at a faster rate. Characters may be added selectively or deleted from the display as required by the program. Second, it operates relatively quietly in the classroom. Graphic displays have the added advantage of being able to format almost any type of problem or schematic very quickly. Students respond either on the keyboard or by using a light pen.

Some disadvantages of a CRT are its relatively high cost, difficulty of obtaining hard copy of a display, and the labor involved in preparing programs. One other factor that might be classified as a disadvantage is the quietness of the CRT. A teletype, with all its motion and bouncing typewheel, seems to hold the attention of a child much more easily than does a CRT on which things appear and disappear very quietly. For older children and adults this does not seem to be as important. They would rather move through the program at a more rapid rate and are bored waiting for messages to be typed out at a rate of 10 to 20 characters per second.

To a course author, the problem of curriculum preparation deserves considerable thought. For example, the third revision of the Stanford drill-and-practice program in arithmetic for grades one to six involved 15 man-years of work in writing, coding and editing. That is, we invested 16 hours in every 10 minute segment of the program. This program was used on a simple system with teletypes. In all, more than 13,600 lessons, tests, and reviews were prepared for that program. At the same time, the amount of effort expended on the drill-and-practice program for grades one to six was considerably less than half that expended on the tutorial program used in the complex system for grades one and two in reading and arithmetic. One of the factors accounting for the difference in amount of effort required by the two programs was the difference in approach between the drill-and-practice program and the tutorial. Another was the amount of labor involved in preparing the necessary curriculum materials.

The advantages offered by an alphanumeric CRT over a teletype or typewriter are speed and relative quietness. Often the fixed character position of the alphanumeric CRT is more restrictive because it does not allow underlining or leaving blanks for answers in the problem format. Frequently, an underline is considered a character as well as the regular alphanumeric set; having fixed character positions prohibits the display of two characters in the same position simultaneously. There are many variations, however, and to discuss each would make this paper of unreasonable length. This problem does reinforce the importance of first defining the subject to be taught, and matching system capabilities with course objectives. Some CRT displays indicate by a cursor the position of the next character to be displayed. This cursor begins at the upper left hand corner of the display and proceeds left to right, line by line down the page. When the transmisson has ended, the cursor returns to its home position in the upper left hand corner. The student will begin his responses here rather than fill in a blank or work through a problem in a format similar to what would be done with pencil and paper. An unacceptable alternative is to present a problem statement with an imbedded blank or response area, to return the cursor to home position and respace it to the blank, row by row. This is time-consuming and very inefficient.

CRT displays with graphic capabilities appear best suited to instructional application. Random positioning of characters permits superscripts and subscripts, underlining, and presentation of such things as long division or complex fractions. Geometric figures can also be displayed and labeled on a graphic CRT.

The Plato III system at the University of Illinois is a complex system which features a modified CRT and keyboard (Huggett, Davis and Rigney, 1968). Course material is stored in computer memory and on slides. Any one of 122 slides may be presented on the CRT. Display graphs can be used independently or superimposed on the slide display at any position desired by the author.

A limitation of this system is the limited number of slides available. Only one set of slides is available at a time; hence, all users must be working on the same program.

Although the system-response time is quite fast, the commands to continue, erase, judge a response for corrections, etc., must be given by the student. Following an incorrect response, a student must erase the display by pressing the appropriate key before he can continue or make a corrective response.

The second complex system is one which has audio capability in addition to the CRT. The audio system may be similar to those discussed above or may use a central bank of tape players. In this approach the system operator loads a tape into the player for each terminal. Students hear the messages over earphones at appropriate points during the lesson. An example of a system of this sort is the IBM 1500 (IBM, 1966), which has a central audio adapter unit that contains an audio tape transport unit for each terminal. Messages are accessed randomly. Message labels can be adjusted to avoid delay, as mentioned earlier.

The next level of complex systems has a film display in addition to a CRT with audio. The film display can be some sort of random-access slide projector or a rearview projector.

The IBM 1500 system used in the Stanford-Brentwood Laboratory was representative of complex systems at this level. A student terminal consisted of an image projector, a cathode ray tube (CRT) with a light pen, a modified typewriter keyboard, and an audio system which played prerecorded messages. Visual material was presented to the child on both the CRT and the film projector.

The CRT can display alphanumeric characters on a 7″ x 9″ screen with 16 lines and 40 spaces per line. A limited number of graphics can be displayed also on the CRT. A total of 192 graphic figures can be used during the execution of any one course. Provision has been made for superscript and subscript positioning of all characters. To gain the attention of the student, an emphasis indicator such as an underline or a moving arrow can be positioned at any point on the CRT screen to highlight selected items. The indicator can also move along the screen in synchronization with an audio message to emphasize given words or phrases.

The image projector is a random-access 16mm. film device that presents a still image, in color or black and white, on a 7″ x 9″ screen. The film images are stored in a cartridge with a capacity of 1024 pictures, any one of which can be selected randomly.

Audio messages are stored in tape cartridges which contain approximately three hours of audio. The student receives audio messages via a random-access control device capable of selecting any message which may vary in length from 1 second up to 15 minutes. In addition to the above components, it is also possible to have a typewriter available to produce some hard copy.

The advantages of a complex system which has CRT, audio, and film display capabilities are the sum of the advantages of each component, plus the advantage of being able to present curriculum in the mode an author deems most appropriate at a given point in the program.

Special features, such as the touch-sensitive screens on the slide projectors used in the Learning Research and Development Center at the University of Pittsburgh, provide a course author with still further adaptive potential (Ragsdale, 1964). The basic equipment for a student station in Pittsburgh's laboratory include a CRT with a modified Model 33 teletype keyboard, a light pen, an audio speaker or earphones, and the back-lighted, touch-sensitive slide projector.

The advantage of the touch-sensitive projector screen is that students may identify, by touch, specific parts of a display. Since the device is under computer control, the correctness of the response can be determined. This is accomplished by means of fine wires embedded in the face of the projector screen.

The disadvantages of the more complex systems are usually operational in nature. If classes working in different subject areas follow one another in close order during the day, a great deal of work is generated for the system operators. Each film and tape must be rewound and stored and new ones installed. New programs must be loaded into the computer, including, perhaps, new sets of graphics or alphanumeric characters. Loading and unloading of magnetic tape and film causes wear and breakage and introduces a degree of unreliability that must be anticipated by a course author if he desires the system to function smoothly day after day. There are many problems of this nature which do not show up during short demonstration programs, but which become of first-order magnitude when a system operates on a daily basis for a school year or longer.

Summary

The aim of this paper was to review and discuss some of the characteristics, capabilities, and limitations of existing CAI hardware configurations. The term CAI indicated that the systems discussed were instructional in nature rather than problem-solving or mediating. For example, systems used by students in mathematics or science classes to solve specific problems were not included. Systems which "mediated" instruction, in the sense of testing performance and recommending future work units for each student (EVECO, 1968), were not included. Computer-mediated instruction via television was likewise omitted. Such a system was in operation experimentally in New York City last year (Staff of *Modern Data Systems*, 1968). After watching the televised lesson, teachers dialed the center and responded to multiple-choice quizzes on push-button telephones.

Each CAI installation seems to have at least one unique feature. Rather than consider each installation separately, systems were classified, generally, in terms of student terminal hardware. Almost no mention was made of central processor capacity or speed. These factors are constantly changing and in nearly every case, the central processor was adequate for the task.

In the final analysis, I agree with Gotkin and McSweeney (1967) and Machover (1968) that one of the most restrictive factors a CAI system can have is the course author himself. The more one works with programs and observes the ease with which students learn to use terminal hardware, the more aware one becomes of still better ways of doing things.

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Reaction Paper

HERBERT J. GREENBERG
Chairman, Department of Mathematics
University of Denver

(The remarks to follow were written in reaction to the original papers presented by Donald Bitzer and Max Jerman on CAI Hardware Development.)

First, I want to comment on Mr. Jerman's paper and present some thoughts on the utility of the systems and approaches he describes, specifically in mathematics instruction. While mathematics is only one instructional area, it can serve as a general yardstick for evaluating CAI systems. For one thing, mathematics instruction spans the entire educational experience from kindergarten through graduate school. Second, mathematics instruction can call into play all of the capabilities of a CAI system, from simple to complex. It is also true that a good deal of CAI effort and experience has been in the domain of mathematics instruction. Thus, the particular frame of reference which I bring to this discussion, namely mathematics instruction, is not as restricted as it might first appear.

Mr. Jerman has listed some criteria for evaluating a CAI system. The first is subject matter (or WHAT to teach), the second, student population (or WHOM you teach). To the words WHAT and WHOM I would like to add HOW, to get the basic question of CAI, namely,

How to Teach What to Whom?

The query "how" requires specification both of the system configuration and of the approach to be taken—drill and practice, tutorial or dialogue (to use Suppes' breakdown).

I would like to indicate some partial answers to the question, "How to teach what to whom?" in mathematics instruction.

First, we note that the two variables WHAT (or subject matter) and WHO (or population) are not independent. We do not ordinarily teach calculus to first graders, nor, if we can help it, arithmetic to college students. We can take into account this dependence by introducing a single new variable corresponding to the various levels of education in mathematics instruction. For our purposes we need only identify three levels. These are related to, but not equivalent to, the elementary, secondary, and college levels.

1. Lower level—arithmetic through introductory algebra and geometry.
2. Middle level—algebra through introductory calculus and finite mathematics.
3. Top level—college and university mathematics.

The WHAT and WHO is clear at each level, although there are sub-populations which present special problems (under-achievers, disadvantaged, etc.). The question reduces to HOW—what configuration and what approach.

In trying to answer this question, there must be a judgment as to the role of the computer in the teaching process at the given level. This may range from assigning the complete task to the computer (no live teacher) to pure drill-and-practice work.

It would be premature and presumptuous at the present state of our development and experience, permanently to assign the computer to any role at any level of instruction, no matter how lofty or lowly. However, our answers must take into account several facts of life we currently face. First, we do not have, nor are we likely to get, full-blown computer programs as package courses that will *at any level* perform adequately all the functions of the teacher. Second, CAI must gain acceptance in the schools as part of the total available instructional resources together with teachers and books. From this point of view, it may even be a poor strategy to attempt to create such full-blown CAI packages.

To me it is realistic to appraise the situation as follows. There is a definite place for CAI in the lower level and middle level of mathematics instruction. Both the drill-and-practice mode and the tutorial mode can be effectively employed. Moreover, referring to the categories of available systems I would say that once the child can read, the simple hardware system consisting of typewriter or teletype is adequate when used in conjunction with printed copy.

I do not see a role for the several approaches to CAI described by Mr. Jerman, in the top level of mathematics instruction—let us say at the level of a legitimate college calculus and beyond. Both the drill-and-practice approach and the programed tutorial presentation no longer seem appropriate at this level of difficulty of material, and a true dialogue approach seems unattainable.

This is not to say that computers, especially those possessing sophisticated graphics capabilities, do not offer an exciting new tool for mathematics instruction at college level courses. However, the mode of use will primarily be student-directed inquiry and free manipulation of the computer and its programed capabilities. This is an approach to CAI which lies somewhat outside of the three Mr. Jerman listed. It is not tutorial in any programed sense and does not pose the recognition requirements of a true dialogue system. For this approach at this level one would desire a complex system with at least CRT and keyboard. Let me return to the role of CAI in the top level of mathematics instruction a little later.

Beyond the roles already cited for CAI, I believe there is a most important and neglected task in mathematics instruction which can be assigned to a CAI system with potential great benefits. This task is *diagnostic testing*. This is rightly the subject of a separate paper and I will only take the time here to say a bit about it.

What I suggest is that all testing in mathematics in the lower and middle levels of instruction be done by computers. Hopefully the computer through individual terminals can do what the teacher cannot, namely:

1. Present uniform tests of achievement (independent of teacher, text, and school)
2. Present tests specific to the skills and concepts
3. Analyze the student's weaknesses
4. Prescribe remedial work

The object in this kind of testing is not to assign a grade, but to make the test part of an educational loop, returning the student to what further instruction in the form of review, drill, and practice he needs. The review and drill work can be administered by the computer through units of CAI. However, the preparation of such materials is a separate task. The student can be given review and drill assignments independently of the computer if CAI material is not available, or until it becomes available.

The use of the computer for diagnostic testing requires specificity of questions with regard to skills and concepts. This assumes that the subject matter can be broken up into suitable units of instruction. This assumption is borne out by existing treatments in the lower and middle levels of mathematics. For example, a study by Dr. Ruth Hoffman of the University of Denver of the eight leading series of textbooks used in elementary schools in the United States, showed that the "scope and sequence" of topics in each series in each year is virtually identical. Thus, standard computerized tests could be introduced, even with present books, with little or no change in the courses of study.

The fact that computerized testing is an individual experience and that the purpose is instruction rather than a grade, seems to me to be of great psychological as well as pedagogical value. It is this kind of value which will help to establish the truly human worth of the computer in the classroom.

Now I want to turn to Dr. Bitzer's discussion of the PLATO IV program. It appears that this CAI configuration will permit any approach to CAI, will be flexible, convenient, and complete for the author and teacher, and is economically feasible. I am satisfied that it would permit the teaching of mathematics at the lower and middle levels quite effectively.

I think, however, that it is necessary for Dr. Bitzer and his associates to be more explicit about the "ground rules" under which the system is to be used to permit 4,000 to use it simultaneously. There cannot be too many different courses or parts of the same courses in memory at any time. If students are using a computational mode there will be proper size limitations. There will be language compiler restrictions, etc. I have discussed some of these matters with Dr. Bitzer and I do not find the current estimates unduly restrictive; nevertheless, it would be most instructive to have more detail so that the estimates made of student demands and computer adequacy can be compared and checked with the experience of others.

Let me return briefly to the teaching of top-level mathematics. I have said that if CAI is appropriate to this level, it would have to be in the *student-directed inquiry* mode. To go a step further, it is intriguing to think of a student working from a mathematical data base in an advanced topic and through the use of utility programs of a kind we do not yet know how to write, composing his own instructional sequences. The role of the author-scholar, as Karl Zinn (1968) points out in his excellent article in *Datamation,* is to assemble the elements of the subject and define the relationships between them.

To imagine the system of Dr. Bitzer in use, for this purpose the data base could include many pages of reference texts. The four-inch-square film plates used to project images on the panel display could be in the form of an ultra-micro-fiche. In that case, rather than 256 pages, a four-inch by six-inch plate could have between 3,000 and 10,000 pages of text at currently-being-tested reduction ratios. This is up to twenty-five 400-page books of information.

I can imagine a student being given a "road map" of information regarding this data base, choosing an allowed sequence of topics to master certain areas of interest to him and then testing himself—asking for help as he needs it. The assumption, of course, is that a student at this level is capable of self-study, which is central to the teaching process.

Reference

ZINN, K. L. Instructional uses of interactive computer systems. *Datamation,* 1968, 14 (9), 22–27.

Reaction Paper

ROBERT KALIN
Professor of Mathematics Education
Florida State University

(The remarks to follow were written in reaction to the original papers presented by Donald Bitzer and Max Jerman on CAI Hardware Development.) [1]

A convenient way to react to the papers by Donald Bitzer and Max Jerman is to consider their remarks relative to five topics: (1) CAI and the philosophy of individualized instruction, (2) student-machine interaction, (3) computer capability, (4) data analysis, and (5) CAI system costs.

Computer-assisted Instruction and the Philosophy of Individualized Instruction

Most discussions of computer-assisted instruction, including the present ones, commit themselves to the philosophy of individualized instruction. This philosophy asserts that:

1. each student should study the subject matter for which he is prepared;
2. each student should study the subject matter at "his own rate";
3. each student should achieve to the extent of his own ability.

These in turn appear to imply that each student should almost constantly be studying by himself. CAI advocates claim that the computer will make all this possible.

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[1] These reactions were written after examining the paper given by Max W. Jerman and three previously published papers by Donald Bitzer.

But many who have tried to program CAI units have found that the hardware (i.e., the computer itself, the terminal, and/or the programing language) seems incapable of doing all the programer wishes. The essential difficulty seems to be a limitation in the type of question one can ask because of the need to obtain a recognizable response. In a sentence, CAI hardware cannot now do, (and may never be able to do), all that a teacher can. For example, how could one duplicate the dialog between tutor and student whereby, by approximation, both parties obtain a full measure of understanding?

Even if such were *technically* possible, the programing would quite likely be impossible. To predict what instruction each student needs, when it is needed, and at the rate it is needed, imposes too much on the programer. How can he *anticipate* all these individual eccentricities when most teachers can not always react properly on the spot?

But, fortunately for CAI as well as improved instruction, the trouble may not arise so much from the limitations of CAI as from the blindly complete commitment of some of its advocates to individualized instruction alone. There seems little doubt that improved learning would result from an appropriate balance of group and individualized instruction, some of each done by CAI. Such could result from an analysis of the following sort. CAI hardware experts should make clear the present capabilities of their equipment. The subject matter teaching and programing specialists should experiment to see what teaching and learning can be done by CAI that cannot be done by a teacher, or at least what can be done better by CAI. It will likely turn out that much instruction should still be done by the teacher with a group, perhaps some by CAI with a group, but certainly a goodly fraction by CAI with individual students at appropriate times.

We have taken this attitude at the Florida State University in our effort to use CAI to help students learn to prove high school geometry theorems. We never thought of programing an entire geometry course. Rather we were very much aware that geometry teachers seem unable to provide each student with the individualized instruction he needs when tackling a difficult proof. An analysis of computer capability and the mathematics and pedagogy of proof has suggested that CAI can indeed help. Our work to date indicates this analysis is correct.

Three Levels of Interaction Between Student and Machine

It has become popular to think of the three approaches to CAI mentioned in both papers: drill and practice, tutorial, and dialog.

There is a great deal of merit to this analysis. But, if misinterpreted, it can lead one away from very effective kinds of instruction, as one might infer from these statements in one of the papers:

> *Drill and practice.*—Each new topic or concept is introduced by the classroom teacher.
>
> *Tutorial.*—A tutorial system assumes the major burden of instruction rather than play a supplementary role like a drill-and-practice system.

There are times when a teacher wants to introduce a topic by having students perform certain computations, make some estimates, experiment in a variety of ways, engage in certain discovery sequences. This can be done nicely with CAI. In a sense, one could classifiy some of such work as drill and practice with a special purpose; yet a CAI program rather than the teacher is introducing the topic, contrary to the first quote. Or one could classify some as tutorial; yet it is not assuming a major instructional burden, contrary to the second quote.

Rather than such a simple analysis, we need to know in detail what the instructional capabilities of a CAI system are. Then we would ask: what kind of teaching strategy or learning experience is needed to develop this mathematical concept or skill at this point in the instruction? Can CAI or a teacher do it better?

Both authors refer only briefly to the "dialog" interaction mode in the sense of student-directed inquiry. One states that a "true dialogue system is not yet in operation," and leaves the impression that new and complex hardware must be developed. This is likely so, in the sense of "a free exchange of questions and answers." But there are times in mathematical instruction when students need practice in selecting the right questions to ask. Simple programs for this purpose could be written with present hardware.

Computer Capability

The essential characteristics of a computer seem to be:

1. huge memory
2. branching
3. computational speed

A survey of the literature would seem to indicate that CAI programs to date have not taken advantage of the computer's computational speed. The present papers mention the numerical computation possibility without giving any examples. Is the CAI type of system such that the computational-speed characteristic cannot be used? If so, this would be unfortunate, for there are many topics in the mathematical curricula of school or college which students would understand better if quick computations could be done at their direction.

Using the *type of terminal* as a basis of classification, Jerman has categorized CAI systems as simple, intermediate, and complex. In discussing the simple system, he mentions some limitations of the typewriter in presenting various problem formats. It is this kind of difficulty that can turn mathematical educators away from developing CAI programs. There are apparently many such difficulties; they call for new hardware development. Programers should not have to make too many compromises.

In this context, Jerman notes that the Dartmouth type of problem-solving system is outside the scope of his paper. I hope it is not outside the scope of this conference.

The intermediate and complex systems apparently have some serious deficiencies. One author comments that breakdowns often occur in such auxiliary equipment as film slides, tape recorders, and films. It is embarrassing to have students run into such problems. Jerman also notes the large amount of work created for systems operators when several classes in different subject areas follow one another in close order in one day. Some CAI personnel have recommended to programers that such devices be avoided because of a variety of other difficulties that can occur, including an excessive amount of time needed to program such equipment into the system. This would be all right if the payoff in learning were commensurate. There are many who would not bet on such a payoff in view of the poor history of film strips, films, and other such media in proving themselves instructionally useful.

On a more philosophical plane as well, there may be reasons to object to such complicated CAI systems. They seem to constitute an effort to mimic with CAI alone all phases of the teaching operation. Previously, in discussing the relationship between CAI and the philosophy of individualized instruction, it was indicated that plugging all instruction into a CAI system in order to obtain completely individualized instruction may not be a good idea. The chief difficulty with CAI at present seems to be our inability to obtain a system that will increase the number of response modes without increasing the programing difficulty. Trying to program multi-media presentations via tacking new media devices onto present systems would seem to be a relative waste of time. Shouldn't the effort be expended on trying to obtain the real advantages of a computer through the development of improved terminals, languages, and/or programs?

One of the papers cites some disadvantages of the cathode ray tube terminal: high cost, difficulty of getting "hard copy" of a display, and programing difficulty. To this, one should add two reports: (1) the CRT terminal has to be close to the computer; and (2) such simple computer-generated graphics as triangles are difficult to program. If true, these are crucial matters that must be solved before CRT is to prove useful. Perhaps the plasma display panel of the Plato Project will overcome these difficulties.

In this context of computer capability, it might be well to react somewhat philosophically to the oft-heard comment that CAI programing is innately difficult. One should not forget that textbook writing is terribly difficult as well. Writing for CAI would be only a few times more difficult if it were merely a matter of branched exposition, with problem-solving to be done by the student separately with pencil and paper.

But, for probably good reason, it is felt that the CAI programer should ask questions and obtain student responses on the computer. Writing the appropriate variety of questions in the right sequence is bad enough—but writing them in the face of a deficiency in computer capability such as response-recognition seems to make the task impossible.

A final remark on computer capability: both authors have mentioned the possibility of inter-student communication. This is an interesting thought. Some mathematics educators claim that academic games can enhance instruction. With inter-student communication on CAI, it would be possible to overcome the lack of control over academic games that sometimes defeats their purpose.

Data Analysis

Both papers mention the possibility of collecting data on student responses. Apparently, in a research context, such investigations as those of Suppes have made considerable use of this capability. In thinking through its use in the teaching classroom, however, it would be well to determine a form of data analysis that would be convenient for teacher use as well as being a significant record of student response.

One paper refers to the advantage of a teacher having a complete reading of each student's response record. Seldom could any teacher have the time for this. Can an individual student's response record be put into a convenient, *summary* form for immediate and intelligent use by the teacher? Can a similar summary be made for all students studying the same unit of subject matter? Is the system capable of doing this without excessive programing time?

Even so, the wealth of information so generated may be so great as to call for the use of teacher aides. Or would it also be possible to generate summary information that would be usable by the student himself?

Costs of a CAI System

Both papers assert or imply that systems can be built that can be available to large numbers of students at the same time without any delays and at economical cost. Just to make sure these claims are understood, it would be well to get answers to some teacher-oriented questions.

1. How many computer terminals should there be in each classroom? Previous discussions seem to imply that each student should have one readily available to him, *even though he may use it only a small fraction of the day.* A teacher should not have to go through scheduling gymnastics in order to use the computer; this was *one* of the difficulties with TV instruction.
2. Under such partial-use situations, will the cost still be reasonable?
3. Will it be possible to have the terminals in the ordinary classroom? Most discussions have been in terms of having one computer serve many students scattered widely in many schools over a large geographic region. So it was surprising to have reported just recently that a newly developed terminal had to be almost on top of the computer.
4. What do all of these partial-use, several-terminals-in-each-classroom, and cost factors imply in terms of how many terminals and computers a school system should purchase? Perhaps even more important, what computer? What terminals?

   An answer to these questions may depend on other capabilities of the computer:
   - a) Can it perform any *testing* functions?
   - b) Can it perform any administrative functions (e.g., scheduling, guidance)?
   - c) Can it perform any problem-solving (computing) functions?
5. An alternative is to make it possible to move the terminals from classroom to classroom. (Certainly it would seem inadvisable to move the students to the terminals.) Is such movement possible?
6. The design for the teaching system proposed by Bitzer needs to be explained further, since it involves crucial decisions. These questions must be answered first:

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a) Is an *inexpensive* data transmission system truly a possibility?

b) What pedagogical considerations make it necessary for the system to drive a "random-access audio-record mechanism, movie films," etc.?

c) It is suggested that using a large computer available to several school systems would have the advantage of holding down the human expense of operating a computer center. Wouldn't a low-cost small computer available to a "small" number of classrooms have the advantage of ready accessibility? If so, wouldn't the operating expense be held down?

Reaction Paper

ROGER E. WYE
Manager, Computer-Assisted
Instruction, Philco-Ford Corporation
Willow Grove, Pennsylvania

(The remarks to follow were written in reaction to the original papers presented by Donald Bitzer and Max Jerman on CAI Hardware Development.)

Max Jerman provided an interesting summary of the state of CAI configuration development from an author's viewpoint. The conclusion to be drawn, in my belief, is that the state of the hardware and programing art is such that the course author is no longer significantly encumbered in his attempts to develop effective programs for Drill and Practice CAI and for Tutorial CAI.

Since the technology appears adequate for the job specified by the curriculum author, perhaps it would be useful for me to comment on characteristics of CAI configurations on the basis of cost effectiveness. The background and origin of most of the observations to follow derive from a two-year association with Project GROW, a CAI system built for the Philadelphia School District by Philco-Ford.

To begin with, it would be useful for my purposes to broaden the scope of CAI activities to the extent suggested by Stolurow (1968) and Zinn (1967) so as to encompass the modes of problem solving, simulation and gaming and author mode in addition to the previously described modes of drill and practice, tutorial instruction, and inquiry. These six modes support the basic aims of CAI which include individualization of instruction, analysis of the learning process and the techniques of instruction under controlled conditions, and assisting educators with development of records and instructional materials. I feel all modes should be considered when one contemplates the kind of investment required by the average CAI system. Perhaps I should even go a step further and include Computer-managed Instruction (CMI) as another potential service to be offered by a CAI configuration. Actually this may in fact be putting the cart before the horse in the long run, since CMI may very well develop into the kind of executive authority that prescribes the kind, amount, and schedule for the other six modes of CAI. This issue need not be debated at this point; it is necessary, however, that the potential user of, or the designer of, CAI configurations evaluate the need and applicability of these numerous facets of CAI in his cost-effectiveness equations so that the most value can be extracted from each dollar he invests.

Secondly, I would like to broaden Max Jerman's definition of CAI configuration to include in addition to hardware, the computer programing system and the application-oriented Author Language, since I believe these items to be of considerable consequence from a cost effectiveness point of view.

On this basis, then, I would like to discuss four general characteristics of CAI configurations that significantly influence cost effectiveness:

1. Capability of initial CAI configuration to expand into, or to be cleanly accommodated by, the system eventually required to handle a total CAI program a few years hence,
2. Dependency of CAI configuration upon operating, maintenance, logistics, and technical support personnel,
3. Ability to accommodate a range of terminal devices to service the wide range of users and tasks related to CAI, and
4. Adaptability to satisfy the information processing needs of an entire educational organization.

Relative to the first point, an easy way to get started in CAI would be to code lesson material via macros or in a popular language such as BASIC, to run under a time sharing executive in a small computer. This could be a cost-effective way of initially providing drill and practice instruction, for example, to a limited number of students. Questions to be asked, however, are (1) will the processor be adequate for foreseeable future tasks or could the processor perform a useful role subservient to a new and larger machine; (2) will the computer programs be useful in the future or will a new operating system be needed; and (3) will the curriculum material be useable or must it be recoded and debugged again for a different future machine? Since a considerable investment is represented by each of these items, one would be well advised to develop a step-by-step plan for performing tomorrow's CAI tasks through the use of today's investments. This is admittedly a difficult problem in view of almost total present-day incompatibility between machines, operating systems, and CAI languages and the rate at which CAI is exploding. Eventually, the noble efforts of a number of workers will tend to standardize CAI language so that the curriculum author has a language with some degree of independence from computer manufacturer, as the scientist has his FORTRAN and as the business programer has his COBOL. Until that happy day the CAI user will be beleaguered by the names of up to thirty CAI languages such as PLATO, LYRIC, INFORM, COURSEWRITER, etc., etc. and can do little more than to use that language designed for the processor/program combination he has chosen; or vice versa. The little more he can do, however, is to make certain that the CAI language he uses will in fact be useful for the different tasks he plans for his system and for the various kinds of terminals he may wish to operate. His future plans, or aspirations, may require that he ask if the language can handle tutorial CAI as well as drill and practice on, for example, a CRT as well as on a teletypewriter. The time to ask this kind of question comes before and not after the time he has committed man-years of effort and tens, and possibly hundreds, of thousands of dollars to instructional materials for CAI.

My second point is that the evaluation of a CAI configuration in terms of its support personnel requirements is far-reaching and is influenced by a large number of factors. For example, a CAI configuration obliged to cover appreciable geography, of which the Stanford System is an excellent example, does well to collect support personnel at a central location and to arrange for the peripheral remote processors and equipment in the system to require minimum maintenance and attention. The reduction of support and maintenance personnel at remote sites is aided by eliminating electromechanical devices, such as tape transports and positioning head disc memories, and by developing simple startup, turnoff, and fault recovery procedures that could be handled by a layman with brief training. As an example, Project GROW uses five computers in five Philadelphia schools. Four schools connect to the fifth, which also acts as the system hub. Tape transports and other electromechanical peripheral devices necessary to system operation, such as reader/punch/printing machines are located at the hub and not in the other schools. A fixed head disc at each of the schools buffers curriculum from central over the data line and stores a copy of the operating system, test and diagnostic programs, and maintenance programs. Results are that the CAI clusters in the remote schools are turned on and off by one of the regular teachers who has received a couple of hours of instruction. In event of difficulty, a telephone chat with the hub is generally successful in restoring operation. Hence, no additional personnel are required in the remote schools as a consequence of the CAI program. Moreover, a centralized system with automatic scheduling reduces the personnel requirements for schedule keeping, disc and tape handling dramatically compared to any other known arrangement. One to two manhours a day is all that is required by Project GROW, for example.

A very large portion of the cost of a CAI program can be consumed by the writing, debugging, and validation of the basic curriculum material. The author-mode of certain CAI configurations permits the construction and editing of some CAI presentations online. This feature may help reduce the cost of curriculum preparation and should be compared to competing features of other configurations relative to the kind of curriculum material being considered. For example, a contemporary configuration permits the construction of drill and practice exercises on an on-line CRT terminal in a rapid and efficient manner in the author mode. The development of tutorial curriculum with complex, unconstrained branching is another matter, however, for which an entirely different configuration of language, program, and hardware may be better suited. The complexity of the curriculum development process and the number and kinds of skills required depends on so many factors that the actual coding and debugging of representative instructional sequences is the only meaningful way to compare configurations in this regard.

Personnel requirements to service the mechanical preparation and revision of curriculum materials can be extensive, particularly when photographic slides, film strips, and audio tapes are involved for multi-media CAI presentations. A great deal of effort is required by the initial art work or dictation, editing, processing, mounting, storing, distributing, updating, etc.; all of which are manifest in the requirement for additional support personnel.

The mission of the processor in a CAI configuration is to make relatively complex decisions at high speed and to feed the results back to the student in a couple of seconds, or less as Max Jerman suggests. However, if a number of photographic slides, or film frames, need to be randomly selected from a population of a hundred or more at a time, delay will result from the basic mechanical problem of handling, identifying, and placing one of many into the correct position for use. The same general problem applies to audio media when the instructional material is stored on magnetic tape. When the student is branched it is probable that the tape transport will reverse the tape motion and scan for the desired message as the tape is rewound. When located, the tape motion is reversed and the message read out to the student. Many clever techniques such as multiple track tapes and special message stacking arrangements help to reduce the random access delay time, but the problem persists of dulling the interaction between system and student. If the student is to be distracted by the delay involved by the computer accessing certain graphical or audio material through mechanical means, then the student might be just as well served by making the selection himself in a book, in a file, or on a record, with significant reductions in equipment, personnel expense, and operating difficulties.

There appears to be general agreement that an audio capability is required for several CAI modes, particularly for very young students and for certain disadvantaged students who are unable to read. An audio capability can provide for (1) introductory explanations of the CAI exercise to follow; (2) general advice or encouragement such as "almost, try again," or "good, your performance is improving"; and (3) relatively brief statements that are unique to the subject matter being presented and that are used to reinforce and remediate the basic visual presentation. Audio services in the first category do not require a tight coupling to computer decisions and could be provided off-line on a group basis, on an individualized dial-up basis, or in other ways that are less expensive and more reliable than, for example, a computer-controlled tape recorder. Audio requirements in the second and third categories need to be tightly coupled to the visual presentation, but could be limited to relatively small vocabularies and as such could be stored in a digital format with the related curriculum material on a disc or tape and could be transmitted over data lines with curriculum material as the CAI configuration requires. The reason that audio can be handled in this manner is that the voice signals have been specially processed into a coded format of binary ones and zeros which permits the material to be processed directly by the CAI processor and associated peripheral devices. The processing tasks include a method for making the audio code as compact as possible for storage economy and a method for converting the code back into an audible state when required by the user. Hence, digitized audio such as used in the Stanford System described by

Max Jerman offers the advantage of storing, distributing, and using curriculum material and audio material together instead of separately. The combination of the two materials simplifies the logistics problem, simplifies hardware requirements, and lessens the need for supporting personnel. Other advantages, incidentally, are a virtually instantaneous response capability and greatly simplified preparation procedures for curriculum authors and supporting technicians. All these factors improve the cost effectiveness of a CAI configuration because requirements for support personnel have been reduced.

Similar arguments hold for graphical material. Pictures for introductory explanation, reference, and added enrichment do not need a tight coupling to the CAI processor and can be provided with easily accessed and inexpensive picture books, slide projectors, and film viewers. These media can be referenced for off-line use by the basic computer-controlled CAI presentations. Closure can be effected by testing during a subsequent session on the CAI terminal. In general, the graphics required for a snappy, real-time interaction with the CAI processor can be satisfied with relatively simple black and white line drawings on the face of a CRT, when used for the purpose of teaching concepts and main ideas. This point needs to be evaluated from an educational point of view and is offered for consideration because of the hardware economies it makes possible. As with digitized audio, specific line drawings can be represented with digital code, can be uniquely identified with chapters of alphanumeric curriculum material, and can be handled together in a single package, thereby eliminating the maintenance support and the logistics support for computer-controlled slide viewers, film strip projectors, or other devices handling special graphical materials in an on-line basis.

My third point is that the cost-effectiveness of a configuration is affected by its ability to match terminal devices to the needs of the user and the task to be done. I've alluded to this before when I suggested that audio and graphical material should be used off-line when not a vital part of the interactive CAI process. There is little sense in paying for and maintaining a complex, computer-controlled capability for which there is no real need. By the same token it is not prudent to use a CRT terminal capable of providing full screen graphics with lightpen and keyboard response capabilities for the presentation of alphanumeric, drill and practice exercises. A teletypewriter might be fine for this task, or as Max Jerman points out, an alphanumeric CRT display could provide higher speed, more quietly—but at greater expense.

When the subject matter is difficult, however, and its mastery heavily dependent upon a high-speed interaction between student and CRT displays of words and diagrams, it is probably not cost-effective to relegate the task to a lower performance terminal because of the disproportionately greater period of time required by the student to achieve the desired level of achievement. On the other hand, some applications of CAI, such as on-line computing, gaming, and simulation have a modest requirement for terminal speed since input and output statements are deliberate and concise. The higher expense of a CRT display could not be justified where a teletype terminal would do the job at a tenth the cost. The user should be careful to make a distinction between the type of terminal needs (requirements) and the type of terminal he wishes to have, for the resulting impact on cost effectiveness can vary over a wide range as a function of the consequent variation in configuration.

For reasons of economy or control, it may be necessary to drive a number of terminals dispersed over a wide geographical area. In general, rapid response, graphical CRT terminals need to be located within one or two thousand feet from its interactive processor because of the data rates between the two. When it is not reasonable to gather a sufficient number of graphic terminals together to justify the cost of a processor, then one may choose to back off to a class of terminals that can be located remotely by telephone lines such as a teletype, or to an alphanumeric CRT terminal, such as described by Max Jerman. The Stanford System he describes has this kind of capability and provides a combination of CRT and teletype terminals to provide different services all over the country. The Philadelphia School District has started an interesting experiment on Project GROW to exploit investments made in curriculum and in system hardware to reach as many children as possible and to reduce the cost per instructional hour. This is being done by slightly modifying for teletype and alphanumeric CRT use material originally prepared for a graphical, high-performance CRT terminal. The modifications consist of the substitution of off-line material for graphics and a general tightening up of the language because of the slower speed of the teletype. The teletype version will certainly not be as effective as the original, nor will it be as expensive. Hopefully, however, the cost effectiveness will be improved for the overall program. On the other hand, an upward compatibility is inherent in the language and programing system so that new material written on a given terminal, such as teletype, can also be used on the same or on a higher performance terminal, such as an alphanumeric or full graphical CRT. The rationale supporting this effort recognizes the tremendous effort required for high quality CAI curriculum material and the necessity to get as much mileage from it as can be achieved. The point I'm trying to make is that the total CAI configuration—hardware, programs, and languages—ought to gracefully accommodate a variety of terminal configurations when a variety of CAI modes and physical arrangements are required.

My fourth and final point is that every dollar of your investment in CAI should be squeezed for every bit of value you can get. If your students cannot be scheduled around the clock to keep the system constantly loaded, then the configuration should be designed to accommodate other users in off hours. An obviously desirable situation is to obtain a body of users whose combined load of off-line and on-line work serves to keep the configuration producing at capacity twenty-four hours a day, most of the week. Useful and related off-line work could be performed for the business side of the educational system along the lines of scheduling, accounting, student records. CMI activities for the educator and statistical computations for the researcher are other eligible off-line activities for the CAI configuration which can contribute to overall cost effectiveness. A necessary action on the part of the would-be user then is to evaluate the characteristics of available CAI configurations in terms of their ability to service as many members of his organization as his political adroitness can gather together in the interest of cost effectiveness.

In summary, my overall reaction to our discussions is that the CAI configurations available today offer a great deal of capability to author, students, teachers, and administrators. A major step forward in the cost-effectiveness of this capability can be achieved by the CAI program director doing some honest-to-goodness planning of what he needs to do and what he would like to do as a function of time. His ability to plan, his ability to consolidate related interests in his school system, and his ability to change traditional ways of doing business are vitally important to the cost-reduction and hardware development efforts of industry in helping to make multi-mode CAI a practical and viable addition to the educational scene of tomorrow.

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PART II

CAI SOFTWARE DEVELOPMENT

DEVELOPMENT OF CAI CURRICULUM

DUNCAN N. HANSEN
Computer-assisted Instruction Center
Florida State University

During the past decade, we have seen the advent of computer-assisted instruction (CAI) and associated curriculum development projects. Even though CAI curriculum development has to be thought of as just beginning, a number of curriculum implementational myths or misconceptions have been identified. For example, an early conception was that a talented university professor would sit at a CAI terminal preparing his text, lecture, or combination for presentation via the computer to his students. Considering that some major institutions have attempted to entice university professors into the CAI "game," the last four years have clearly documented that the efforts to attract professorial authors are meager at best and teeter on being colossal failures. The problem may be one of attracting the right authors to the CAI terminal and persuading them, as Fred Termain attempted to persuade Stanford professors, that writing a page a day should result in the preparation of one textbook per year. Unfortunately, the complexities of CAI course development far transcends that of the preparation of a conventional textbook. Given the recognition of this complexity, the major thesis of my presentation can be summarized as follows: CAI course development requires extensive role differentiation, effective project planning, and efficient management techniques in order to maintain optimal implementation.

Documenting this claim of complexity, at least eight major factors can be cited that determine the developmental rates of a CAI curriculum project. Subsequently, some conceptions concerning the "systems approach" will be characterized to describe an ideal CAI curriculum developmental pattern. Related to the "systems approach" will be an exploration of the management techniques required to cope with the complex world of CAI. To elaborate upon the functional complexity of CAI developments, ten significant professional roles necessary to sustain a reasonably sized CAI curriculum effort will be described. Since CAI offers an opportunity to collect extensive amounts of behavioral data, a review of data analysis and data management techniques will be included. Finally, a review of economic and cost-effectiveness factors will be considered.

Factors of CAI Developmental Rates

CAI curriculum developmental rates are a function of at least eight major factors. Parenthetically, more insightful investigators within this field could cite many omissions within this list. At least these eight factors can be acknowledged within anyone's list of causative factors in CAI curriculum developmental rates.

1. *The clarity of the behavioral objectives for the CAI curriculum will determine the speed with which a project will be developed.* To cite just an example from applied mathematics, I have heard extensive arguments as to the nature of and approach to probability theory. The mathematician tends to dismiss it as a relatively uninteresting topic. The statistician considers it the keystone of his discipline and spends great effort in training graduate students to prove the theorems of various axiomatic approaches, such as deriving characteristic functions for a host of continuous distributions. The applied statistician considers probability theory a useful tool in considering those distributions that have reasonable matches with real world phenomena. In turn, the behavioral scientist uses probability theory as a useful set of conceptions underlying statistical procedures while, alas, the poor graduate student considers probability theory a useless sojourn within his first introductory statistics course. The point is that a potential CAI-based probability course would have to clarify the desired behavioral objectives in order to proceed in an expeditious fashion. Ambiguity of behavioral objectives only results in ambiguity of curriculum construction and conflicting approaches.

2. *Terminal criterion performance levels will determine both the instructional sequence as well as the complexity of the CAI curriculum.* To use a simple example from the Stanford Mathematics Project, would one be satisfied if the student could demonstrate at grade two the successful addition of two columns of double digits, or does one want to specify latency criteria to the perform-

ance level? Either criterion for terminal performance will imply an instructional strategy (e.g., remedial explanation loops for error responses as opposed to timing schedules for speed criterion) while the combination implies a different CAI instructional approach (combinations of explanation sequences mixed with dull sequences). The point is that varying the desired terminal performance level and associated criterion test items will vary the complexity of the CAI curriculum.

3. *The range and frequency of varying response modalities can effect the rate at which CAI curriculum can be implemented.* The response modality of speech analysis is unfortunately well beyond the capability of current CAI technology. At the other extreme, the use of multiple choice formats allow for expeditious preparation of problem types. Moving from either of these poles, one finds that complex response analysis schemes for the answer-processing of the symbol strings generated by a student can introduce a whole host of computer systems problems. To illustrate within the COURSEWRITER language context, "Can the author anticipate all of the incorrect responses, and how important is this?" Or, how important within plane geometry would all the combinatorial paths to a constructed proof be to the development of legitimate conceptual formation? If one requires proofs to be developed on the surface of a CAI controlled CRT screen, one expects a type of equipment and a CAI operating system which requires extensive programing sophistication. On the other hand, the problem is simply resolved by having the student construct demonstrations of proofs in the conventional paper and pencil fashion and enter the informational conclusion on a screen via light pen. A simplified approach saves greatly in the development of CAI curriculum while complex response analyses requirements place unfortunate handicaps on the developmental rates of CAI curriculum.

4. *The instructional sequencing strategy will affect CAI course developmental rates considerably.* To use logical proofs as an example context, one can provide the student with a tightly structured valid step in a proof of a theorem and ask only for its justification. This forced-choice instructional process is quite simple to implement on CAI and appears like linear sequences found in printed programed instructional materials. On the other hand, a highly complex combinatorial search for all the different possible valid and invalid ways of deriving a proof is rich-appearing instructionally, but almost impossible to implement on a CAI system. The computer programing problem becomes so unmanageable that minimal goals of the curriculum project could not be fulfilled.

In a related way, the empirical evidence on complex remedial CAI sequencing remains marginal at this time. Most complex examples of remedial branching structures appear to improve learning outcomes by fifteen percent or less, a behavioral result easily accounted for by practice effects. A more promising instructional sequencing approach is to allow a student to self-select remedial material as opposed to automatic branching at sub-criterion test points. Recent experimental results suggest that college students are capable of self-selecting learning materials to resolve conceptual weaknesses and to improve performance. This type of instructional sequencing strategy may provide an efficient and elegant solution to the branching, testing problem in CAI.

5. *The variety of multi-media utilized in a CAI course will determine the implementation rate and the logistic ease of the instructional process.* Many a CAI project has been bogged down in the problems of developing audio tapes or discovering the nightmarish complexities of producing a color 16mm film. In turn, the requirements of having multiple copies of films and audio tapes to solve the queuing problems when CAI field testing a new curriculum has delayed many a revision cycle. In essence, the most convenient, economical, and available solution to media requirements usually proves to be the best solution for implementing CAI curriculum.

6. *The number of revision cycles required to develop an "acceptable version" of a CAI course remains an unanswered question.* One would hope that the clarity of behavioral objectives cited above would aid in determining when curriculum revision cycles should cease. To offer just a personal example, FSU has developed a CAI introductory physics course for non-science majors. Field testing on two occasions has clearly demonstrated that student terminal performance is increased by approximately twenty percent with about a fifteen percent saving in instructional time in comparison with the conventional course. Even with this demonstrated superiority of the CAI course, one of our principal physicists has recently recommended an extensive number of revisions in order to "provide a better course for the students." Thus, the issue of revision may be very much like the issue of when should any textbook or curriculum undergo change for the sake of improvement. One would hope that the behavioral evidence might decide the issue, but then the vast majority of CAI learning responses remain unanalyzed due to limited data management systems within the computer. In essence, the revision process within CAI course development will be a major difficulty for any new curriculum project.

7. *The degree of sophistication of the CAI operating system is*

highly critical in determining the rate of development of the CAI course. The limitation of CAI operating systems and their continual flux as they undergo improvements can create phenomenal delays in CAI course development. CAI systems programers are always "just around the corner" from solving all of the current problems. Unfortunately, the turning of that corner reveals a whole new host of problems reflecting both the engineer's desire for elegance and efficiency and the curriculum writer's desire for complexity. Large CAI projects probably should only be implemented on highly developed, well-documented CAI operating systems. The development of a new CAI operating system typically takes two calendar years and twenty man years of effort.

8. *The degree of experimental variations for a CAI course will determine the rate with which a curriculum project successfully reaches closure.* There is growing evidence that more extensive CAI experimentation should be fostered during this coming decade. To cite just one example, the behavioral data collected within a junior high science CAI course context indicated that the student's anxiety level is an excellent predictor of his conceptual development. More explicitly, those students with observed low CAI learning rates and performance levels had exceedingly inflated self-reported anxiety scores. The converse held in that low anxiety reports are associated with high performance levels. How personality traits and associated behavioral patterns interact with learning within CAI is an almost unexplored topic. One can speculate on a future in which anxiety is treated concurrently with mathematical instruction. On the other hand, each experimental variable being processed within a CAI project increases the manpower requirements. Usually, there is little or no spare time or resources available to experiment if one is to meet the CAI project deadlines.

There are undoubtedly many additional factors that determine implementation rates for CAI course development, but trying to calculate the probabilities and loss coefficients for these eight factors alone exceeds my utility analysis capability. How the complexities of these factors interrelate is certainly yet to be determined and undoubtedly explains why there are so few completed CAI curriculum units available.

Turning now to a more positive view of CAI course development, one can utilize the "systems approach" to resolve many of the complexities of this computer instructional world.

The "systems approach" has evolved as a set of ideal implementation procedures which can be followed in order to develop effective learning materials which maximize the conceptual development of the students. If you will turn your attention to Figure 1, the essential features of the model are laid out. The first step in the process is one of describing the instructional problems being addressed. Within CAI course development, it is useful to list the specific problem on which the CAI learning interaction will focus. If these problems can be identified in terms of such behavioral phenomena as test scores and prototypic homework responses, the CAI project will be farther ahead in that an initial baseline of performance will have been established for comparative purposes. The availability of baseline data is exceedingly useful in trying to decide whether some early field tryout data is substantiating the improvement in performance.

As the schema suggests, a task analysis of the curriculum concepts to be taught to the student should be performed. Task analysis is a complex, logical analysis procedure by which one delineates the relationship between topics which are to be covered in instruction. Any pre-supposed hierarchy or logical relationships should be re-

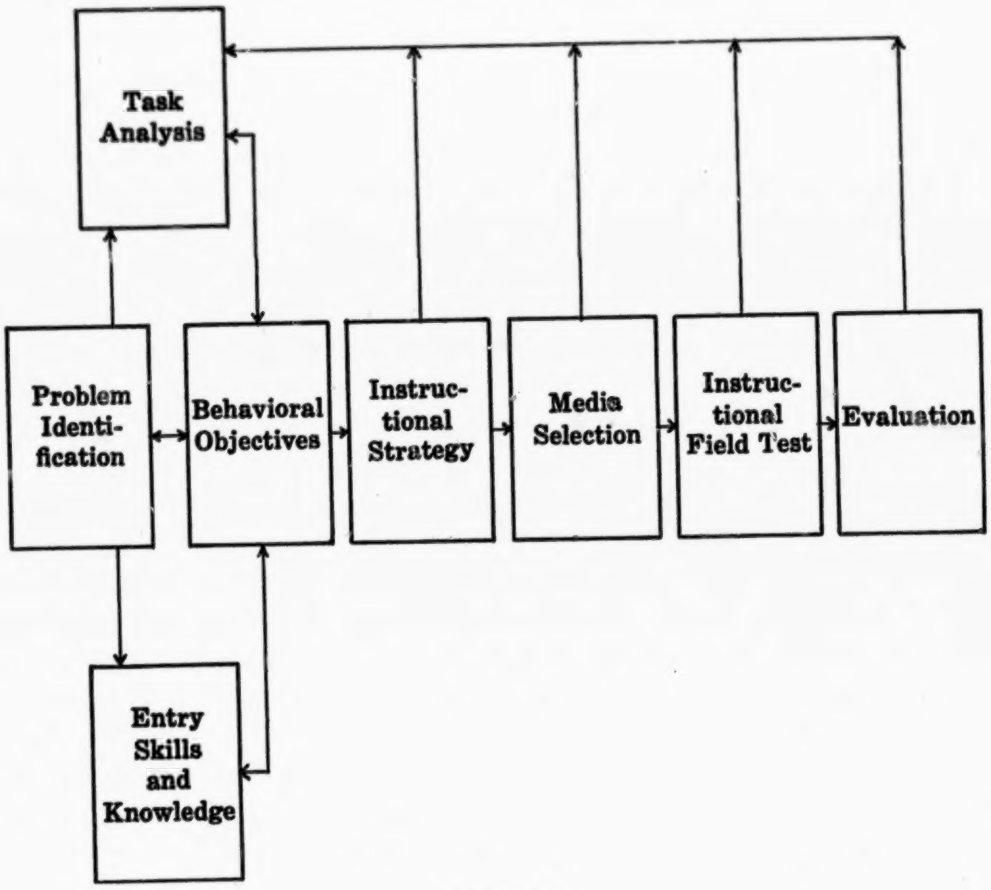
Task Analysis
Problem Identification
Behavioral Objectives
Instructional Strategy
Media Selection
Instructional Field Test
Evaluation
Entry Skills and Knowledge

FIGURE 1

vealed. In simple terms, the task analysis should reveal an outline of the curriculum structure as it is to be taught.

Concurrently, the baseline data should be utilized in specifying reasonable assumptions about the skills and performance levels of the students as they enter the CAI instructional process. These performance levels are commonly referred to as entry behaviors. Entry behaviors represent a characterization of the heterogeneity of conceptual development on the part of the students and how this impinges on the conceptual sub-components within the task analysis. In essence, entry behaviors should indicate where the students are at the beginning of the course, and the task analysis should characterize the various conceptual topics to be mastered by the students.

The information from the task analysis and the entry behaviors are then utilized in formulating behavioral objectives. Behavioral objectives are hypothesized propositions about what could be and ought to be achieved in the prescribed instruction. In regard to the modifier "behavioral," these goals of instruction should be stated in terms of observable activities which the students can demonstrate upon completion of the CAI course. Behavioral objectives should include the conditions under which the terminal performance should take place, as well as an indication of the desired performance level. Without a doubt, the process of formulating behavioral objectives is far more complex than portrayed by anyone to-date. If you view them, though, as hypotheses, one has the advantage of utilizing the feedback processes within the model to alter them to a reasonable characterization of what is possible within a CAI course. The ultimate relevance and validity of the behavioral objectives can only be judged when the whole valuative procedures of the project have been completed.

Moving on to the next step, the behavioral objectives should be structured within a sequence which reflects one's pedagogical strategy. The instructional strategy to be employed should relate to a hypothesized set of psychological states through which the student would pass. First, the student should be given a recognition of the learning expectancies to be covered within a sub-component of the CAI course. These psychological expectancies will provide involvement and commitment on the part of the learner to obtain desired behavioral objectives. Without this psychological commitment, the instruction will be doomed to failure. Having gained involvement, the information must be then presented in units relating to the prior knowledge and problem-solving skills of the student. The algorithms for these problem-solving skills should be clearly related to the sequential steps found within the instructional strategy. For example, long division can be analyzed into a number of sub-processes such as multiplication and subtraction. Given that a student has mastered the sub-component elements, then the more involved algorithm of long division can then be presented in artful instructional segments. As a last feature, the instructional strategy should provide frequent conceptual closure and the self-realization by the student of having gained competency over the intended course content. The psychological requirement for frequent closure is one of the most overlooked aspects of evolving an effective instructional strategy.

As an interrelated aspect of instructional strategies, one must also keep clearly in mind the available medium of presentation. The process of selecting media is still in a relatively crude state. Obviously, the media utilized for informational presentation should be as contiguous and similar to the response modality as possible. For example, the cathode ray tube can be used to present geometric line drawings and the light pen feature of a CAI system can be utilized for responding on its surface. On the other hand, simple typed presentation of numerical problems can be utilized with the simple numeral array of a typewriter keyboard response. Obviously, one should use the limited evidence from the behavioral sciences in order to relate the students' informational processes capacity to the media features.

The following guidelines have proved useful in our laboratory at FSU:

1. When attempting to provide for maximum acquisition of conceptual material, one should maximize the sensory channel inputs. For example, one might use TV or complex film presentations to maximize the richness of the sensory redundancies.
2. When allowing for both acquisition and intellectual problem-solving, one should restrict the informational source to a single channel. For example, in problem-solving situations, one can utilize slides, graphic presentations, and concept films.
3. When building problem-solving algorithms and providing for long term retention of conceptual matter, the psychological requirements for feedback and correction are highly important. In addition, one tends to utilize the interactive feature of the CAI system in order to maximize sufficient practice in order to insure mastery.
4. When faced with evaluative decision-making concerning the student, especially in determining successful mastery of sub-components within the course content, one typically utilizes the real-time student history record features of a CAI system in order to aid in this decision-making process. In addition, we also utilize the

student's own self-selection processes to aid us in making more insightful decisions.

5. One by necessity should consider the logistics of the instructional process in that one considers how the student will move from one particular device to another. Interruptions in the learning process are well documented to interfere with acquisition rates. Thus, the process of media selection can be artfully resolved by following some of the reasonably good prototypes that currently exist.

As portrayed in the model, the next step is a field test or the providing of actual instruction to a carefully selected sample of students. As a final outcome, the response data should be sufficiently analyzed and evaluated in order to provide information all the way back to the structuring of the conceptual components within the task analysis as well as the development of more refined behavioral objectives. As the arrows within the diagram imply, this is a complex process involving many iterations commonly referred to as revision cycles. As mentioned above, the number of revision cycles is a complex issue in its own right and relates to the relationship between the initial problem identification and related baseline data plus the terminal performance level at the end of a given revision cycle.

Management Techniques

Obviously within such a complex process as this, good management procedures have to be utilized. In terms of planning, FSU typically utilizes PERT (Program Evaluation Review Technique) in a new project. Laying out a project within a PERT diagram before initiating its full implementation aids in recognizing the multitude of steps necessary in order to successfully complete the commitment. In addition, a PERT diagram clearly specifies parallel work efforts and the need for good coordination. It should also prove useful in attempting to analyze one's cost as well as estimate the amount of manpower needed under the best and worst conditions.

The problem of cost analysis is one which is only beginning to receive attention. Attempting to estimate the cost of a CAI course development project is still very much in its infancy. While we are starting to have a clearer insight as to the manpower requirements, estimating the amount of time needed to successfully iterate through the systems model is well beyond accurate predictions. Fortunately, the systems model provides for certain adjustments in developmental rates which, in turn, can allow one to adjust cost in order to fit the proposed budget. But then, I will have more to say later on the topic of cost development of CAI curriculum material.

Perhaps most importantly, people working in CAI need to be excellent pragmatic problem-solvers. I find an inordinate amount of time being spent on issues relating to "how best to build a student carousel," or "how does one get the carpenter to install a wall that is essential to reduce noise levels in the instructional environment." These are pedestrian problems, but in many cases can hold up projects at critical times and impinge on the morale of the project group.

Roles Within a CAI Project

In reference to the complexity of functions portrayed within the systems model, one can quickly perceive that a number of differing kinds of professionals are quite essential. First, one needs excellent talented scholars who can assist in the task analysis. The more insightful these scholars are in looking at alternative ways of structuring the logical relationships of the concepts, the more fruitful the CAI project will be.

These content scholars will find themselves primarily interacting with the behavioral scientists, also associated with the project. The behavioral scientists should provide the insights of relating the task analysis and the entry behaviors to the behavioral objectives. Their role should constantly be to provide both reasonable criteria of how to observe the behavior as well as helping to specify reasonable criterion test items that relate to the desired terminal performance.

Since the talent of the above two groups is in exceedingly short supply, most projects find that full-time curriculum writers are essential. These are talented writers who communicate effectively on the level of understanding of the involved students. Writing is an extremely demanding job and most CAI projects have found that full-time curriculum writers are the most successful way of insuring course development.

After the learning materials have been written or specified, they will then go into a production phase. In terms of CAI, a full-time coder to enter the systems operating codes as well as the instructional text will prove most efficient in quick development. In turn, technical staff relating to films and television presentation will also be required. During all this process, there will be a need for a computer operator and a systems programer who can adjust the features of the CAI operating system in order to maximize the ease of implementation. The availability of a good CAI systems programer is highly critical in determining the effectiveness of the implementation process.

During the actual process of instruction, there will be a need for proctors as well as data analysis programers. Quick and efficient data analysis allows the cycle through the systems model to take place at the rate ideally desired. Moreover, there needs to be a managerial and clerical support staff to provide maintenance functions for the group. Good management in monitoring of the project can be highly critical as to whether short and long term goals are achieved.

Within academic environments, there should be an array of graduate students who provide two contributions to a CAI project. First, the graduate students will provide back-up personnel and excellent problem-solvers. They can resolve the multitude of little problems that seem to plague all CAI projects. More importantly, graduate students will raise questions about the overall procedure, and generate small research experiments that contribute in the formative stage of a CAI project. This investment in graduate students and concurrent experimentation should not be minimized and is far more important to the overall quality of the final CAI course than most people have been willing to acknowledge.

Data Analysis and Data Management

Turning now to the data management issue, the CAI operating system should have a general data management system available which allows for the organization of the behavioral responses into a general file structure. This general file structure is an exceedingly important feature in that the data has to be analyzed by necessity from a number of different points of view. For example, authors tend to be primarily interested in item statistics on given frames within the curriculum. The variety of item statistics and related print-outs, range all the way from a complete listing of all responses to summary statistics. Quick availability of this information will allow the curriculum writers to proceed ahead in a most expeditious fashion. Secondly, the file structure must be amenable for running comparative analyses with the starting, baseline data. The comparative analyses allow the project team to decide whether progress is in fact taking place, and which of many variables may be determining performance levels in some of the early versions of a course.

In terms of more sophisticated analysis, most CAI investigators are performing causative type analyses, utilizing linear regression techniques. The data structure found within the general file system typically is organized in a matrix fashion in order to generate variance and co-variance matrices which can be in turn regressed on a varying number of dependent variables. These linear regression techniques are extremely useful in gaining insights as to which portions of a course or related variables are having major impacts in determining the kinds and types of final performance levels.

One of the great potentials of CAI data is the sequential tagging of each response. Sequential analysis of the pattern of responses can prove highly useful in thinking through the relationship between the task analysis and the actual terminal performance. Ultimately, quantitative models can be built for the learning process. These models provide precise ways of altering the task analysis sub-components in order to give a better account of the actual behavioral features found within the learning process. In addition, a well-organized data management system can prove useful in terms of estimating cost factors within various portions of the course. As is typical within economic analysis, one is relating input costs to outcome gains. A good data management system provides a facilitating manner in which to perform these calculations.

Economics of CAI

Unfortunately, the available information on costs of CAI curriculum developments of various types are exceedingly limited. Most of the projects which have been developing CAI curriculum over the last five years have not included a section on component costs for various curriculum units. One often hears the figure of $10,000 per hour to prepare an instructional hour of CAI materials. Even in the most affluent case I have come across, I fail to see how this is derived. Allow me to cite two examples of research projects performed at the CAI Center at Florida State University and their related costs.

The first example is a lower bound in an estimated cost figure. Within the Intermediate Science Curriculum Study Project sponsored by the U.S. Office of Education, there is a CAI evaluational effort. Keeping in mind that the seventh-grade science materials are being prepared for CAI presentation in order to closely parallel the informational structure and instructional strategy found in the classroom, the total cost to prepare the 180 hours of material was $34,865. This total figure yields an approximate preparation cost of $12 per instructional hour. These cost figures include personnel costs for three graduate students, a full-time CAI coder who enters the material into the CAI system, and one-fifth of a science education faculty member's time. In addition, the cost of $2.13 per instructional hour for student presentation has been added in. This hourly figure includes not only the rental charge on the IBM 1500 terminal, but in addition, unit record equipment charges, laboratory remodeling costs, new equipment, maintenance and janitorial service, and some portion of the general administration of the CAI Center. Thus, one can see that there are economical approaches to the preparation of CAI materials.

A more realistic set of cost figures are presented in Table 1. These figures are derived from the collegiate CAI physics course developed at FSU over the last two years. I have attempted to break down the costs in approximate categories so that you can relate component costs to steps within the systems model. The only unusual and extraordinary cost was the $55,000 necessary to develop the data management system for the 1500 CAI computer. This is a one-time cost and can be shared by other installations having the same equipment configuration. The breakdown in Table 1 can be usefully analyzed by you in terms of trying to estimate cost factors for a fairly major one-term CAI course. Undoubtedly, these cost figures should be thought of as statistics which will fluctuate de-

TABLE 1

COST ANALYSIS FOR A COLLEGIATE CAI PHYSICS CURRICULUM DEVELOPMENT PROJECT

Category	Item Cost	Total
Curriculum Preparation		
Behavioral Scientists	12K	
Physics Writers	12K	
Physicists	6K	30K
CAI Coding		
CAI coding personnel	12K	
Computer time	10K	22K
Film and Graphics Production		
Art work and service cost	6K	6K
Computer Programing		
Data Management Programing	55K	
Data Analyses Programing	15K	70K
CAI Instructional Cost		
CAI Computer Costs	15K	
Proctors	3K	18K
Experimentation		
Graduate Students	24K	24K
Office and Clerical	10K	10K
University Overhead	60K	60K
Total	240K	240K

pending on the kind of CAI course being considered. Even utilizing the total project cost, including university overhead, the forty hours instruction (30 hours of existing material plus 10 hours of review material) yields a CAI production cost figure of $5,980.00 per instructional hour. Since we have no other project to compare these cost figures against, I can only offer them to you in a descriptive vein. Undoubtedly, within the near future we will have a much better picture as to the relationship between CAI curriculum costs and types and kinds of curriculum materials.

Conclusion

After this lengthy sojourn through the world of CAI curriculum development, hopefully, you are thoroughly impressed by the CAI complexities mentioned during the introduction. A realistic appreciation of the requirement for professional and functional role differentiation should be clearer. In addition, much of the discussion hopefully indicated the requirement for effective project planning. Undoubtedly, more efficient management techniques will develop within the next decade for CAI curriculum development. These should be watched carefully as management aspects of highly complex research and development projects usually can contribute considerable savings if approached from a pragmatic point of view.

IMPLICATIONS OF PROGRAMING LANGUAGES FOR MATHEMATICS INSTRUCTION USING COMPUTERS

KARL L. ZINN
Research Associate, The Center
for Research on Learning and
Teaching, University of Michigan

It has been some time since I was a member of a mathematics teaching staff, and I am not now writing any significant amount of computer-based curriculum materials in mathematics. I have made a modest and by no means complete survey of the area. Because I am not associated with any vendor, nor any one curriculum project, nor with mathematics instruction in particular, I can speak quite freely without fear of offending my boss or co-workers. My point of view as an "outsider" should provide useful perspective.

Attached to the proceedings you will find descriptions of math instruction materials developed for computer presentation, samples of actual lessons and their use with students, and reports describing the curriculum development effort and opinion about what contributions the computer has made to instruction. Only documents not previously available are attached to the proceedings; reports easily obtained elsewhere have the most convenient source listed.

I have spent a substantial amount of time in the last ten years considering instructional applications of computers, and background for this paper comes from many sources. Among my current activities perhaps the most relevant are studies of programing languages and instruction strategies. (This work has been supported in part by an Office of Naval Research Contract with EDUCOM, Interuniversity Communications Council, Boston, and preliminary reports appear in the proceedings of IFIP and ACM meetings in August of 1968.)

First I am going to discuss the variety of potential computer uses, with emphasis on three modes: author-controlled instruction, simulation and gaming, and learning tools. I will be paying particular attention to examples from mathematics instruction but when I do not know of a mathematics curriculum which exploits certain computer capabilities I will have to fill in from other subject areas.

Second I will list some contributions which I think a computer should make to individualized instruction, and the assistance it should afford the different users: student, teacher, and curriculum writer.

In the third part of my presentation I will be talking about characteristics of programing languages. I will try to simplify a rather complex topic by summarizing languages in four categories, and presenting only such differences as appear to me as a curriculum writer to be essential. We will discuss the implications of language types for different curriculum projects and the relationship of language to project purposes, staff and budget, etc.

Modes of Instructional Use of Computers

You will have noticed that I avoid using the initials "CAI" or "CBI" or even "CAL," although I have always endorsed Ralph Gerard's emphasis on aids to learning. Since acronyms tend to become associated with one manufacturer, computer system, or research and development project, they sometimes restrict one's view. I want you to consider a variety of applications, including computer assistance for problem solving, simulation, or even preparation of text materials. Although manufacturers must limit the scope of applications in order to market a system which is economical to operate, the general discussions of this conference should not be restricted to any one mode of computer use. One day the manufacturers may discover that variety and flexibility are not necessarily incompatible with economical operations.

Last year in the *Review of Educational Research* (Zinn, 1967) I discussed seven or eight modes of use for computers in instruction and provided an extensive list of references. For this conference it is useful to reduce that earlier analysis to three groups or classes of computer use: author control, simulation and gaming, and scholarly aids for learning and problem solving. The three modes discussed by Max Jerman all fall in the first category, at least as I understand "dialogue." For a general introduction to instructional uses of computers, see the "guide to the literature" (Zinn, 1968*a*), and in particular the special issue of *Scientific American*, September 1966, on Information, Alan Riedesel's article in the *Arithmetic Teacher* in January 1967, and the September 1968 issue of *Datamation.*

The CAI laboratory at The University of Texas, Austin, can show you an example of diagnostic testing combined with some tutorial material; it is part of a self-instruction package for math skills preliminary to a college chemistry course.

One of the early CAI projects at The Pennsylvania State University prepared a course in modern mathematics for teachers; and a later project in vocational education produced some units of mathematics instruction. These materials are perhaps best characterized as computerized programed instruction.

Computer use for a kind of constrained conversation is characterized by an attempt to encourage additional initiative on the part of the student, and to provide some relevant reply whatever he may say.

Max Jerman included an excerpt from Suppes' computer-based logic course in which the student is allowed to enter directions to demonstrate a proof. Easley (Easley, Gelder & Golden, 1964) at the University of Illinois prepared a basic package for executing a variety of problem-solving exercises. Another example is a problem-solving exercise in physics programed at MIT (Taylor, 1968) in which the acquisition of information by the student alternates with his attempts at specifying a solution. The program was designed so that it confirms what was "understood" by displaying each time the words which were recognized in the student's message. In all cases, however, the conversation remains under the control of the curriculum writer or computer programer.

Many hours of drill and tutorial materials have been generated. One can assign drill to large numbers of students with reasonable confidence that it will be useful; and it is easy to serve many simultaneous users of drill exercises on a relatively small computer. However, if economic criteria are important, alternate ways of achieving the objectives of the computer-based drill exercises must be considered. Skills might be acquired more efficiently through paper-and-pencil exercises, or more effectively as the side benefits from more complicated problem solving tasks aided by the computer.

The mode of computerized programed instruction or computer-based testing is familiar and comfortable for a college professor interested in educational technology. However, the benefits unique to computer presentation of text and test material have not yet been demonstrated. Some advantage beyond novelty is anticipated because the writer of the instructional materials is able to specify the processing of constructed responses, complex branching strategies, and appropriate concealment and control of material for each student. However, most of the computer-based lessons have made little use of capabilities which cannot be accomplished with printed formats for tests and programed instruction. The computer may have played a significant role in improving instruction by helping the author to more careful organization, testing, and revision of materials, but in the end his self-instruction package may be presented to students almost as effectively (and with considerably less time and cost) in booklets and audio-visual modules.

Unfortunately, a significant part of the $200,000 typically invested in a one-semester computerized course is spent for implementation on a particular computer system. Computer uses in this category have a place, but there may also be much misuse.

Simulation and gaming

The author of an instructional exercise in this category has designed a model which students can explore to test their understanding of some set of concepts. Mathematics plays an important role in simulation of real problem situations in business management, government planning, international relations, career planning, chemistry, etc. I have not identified clear examples of the use of this mode for mathematics itself. I recommend it because the designer of the exercise can manipulate the situation so that a student must handle one concept or relationship before turning his attention to other more complicated ones which depend upon it. The work of Glenn Culler (1967) on teaching concepts of analysis and approximation may be interesting in this connection.

Instructional games typically place the student in a situation which is less realistic and more competitive than simulation. A game may provide specific payoffs and usually introduces potential conflict and cooperation with other students. The purpose of playing instructional games is usually to perfect the skills which are considered necessary to play a winning game. Some important but usually incidental benefits concern learning to work with other students.

It is expensive to play these games through a computer communication and processing device, and it may be difficult to justify the additional cost. Instructional gaming has already had considerable success in the non-computer mode. At a session on simulation in CAI last January (ENTELEK, 1968), Layman Allen made a good case for non-computer simulation and computer non-simulation. I will not go into the details of his argument here, but I worked with him on a sample exercise to use the computer to train people to play his equations game without the computer. Before a general program could be written he produced a non-computer design to accomplish the same training with much less expense and considerably improved distribution!

Gaming and simulation may not have exploited fully the potential advantage of social interaction and the richness of the learning environment, but I would not wish to lose the opportunity through computerization.

The computer as a learning tool

On-line tools for computing and problem-solving should be as useful to the student as they are to any other user of a computer. Perhaps the interactive mode is more important to a student (or any inexperienced user) because it provides greater opportunity for training and diagnostics as they are needed. Before most members of the present school population conclude their productive lives, computer-based information processing resources may be as available as the telephone and television.

Notable examples in this category of use for mathematics instruction include projects involving the Massachusetts Board of Education (Richardson, 1965), the Liberty Schools near Boston, Bolt Beranek and Newman (Feurzeig & Papert, 1968), the Philadelphia Public Schools, New Hampshire schools near Dartmouth College, and other universities and regional service centers.

I would not try to count the many programs in computer appreciation and computer programing in elementary and secondary schools, and I have in mind something more than that for this category. The designer of the computer-based learning exercise should give careful attention to specific instructional objectives and to computer aids for their achievement if he hopes to document his hypothesis that the richer environment and greater responsiveness of the computer lead to many other desirable results in addition to acquisition of facts and basic skills which might be accomplished with author-controlled drill.

In summary, what modes have I found in computer-based mathematics curriculum materials?

Drill and computerized programed instruction have been widely used at considerable expense when compared with non-computer procedures to achieve similar student practice or self-testing. Constrained conversation has been used to a limited degree; it is even more expensive to prepare and operate. Simulation and gaming have been little used; problem solving is widely used in computer science curriculum but rarely with automated assistance for the student. Other learning tools have not been touched; perhaps they are less relevant to the computational and conceptual skills of mathematics.

A significant dimension which should be considered in the selection of curriculum procedures for a particular project is that of control. Computer-based lessons differ in terms of the control the writer has over the student's course of study. At one extreme the student can only follow the program; typically he finds himself more restricted working at a computer terminal than he would be with a textbook or set of drill exercises in hand. That is, the writer has not provided the computer instructions which would permit the student to look back, review, or skip ahead as he does with printed materials. Concealment and control are desirable in some situations, and curriculum designers have used such facility to reduce inappropriate skipping about or other distractions. Such control is also an advantage when the lesson designer is testing his materials and wishes to know exactly what each trial student has seen and when.

Further along this dimension of control, a lesson responds to the student in set ways, but allows for a greater range of input from the student, and gives him opportunities to change the topic. It is much more difficult for a curriculum writer to be successful with this type of programing, and relatively little has been done in this category.

The other extreme is characterized by almost complete user control. The computer is programed to serve the student as a tool in the management of the information necessary for problem solving. The most common use is as a conversational computer, that is, for calculations and other immediate processing in response to directions from the student. A student also can be given access to large files of information to retrieve and rearrange facts as useful for his study.

Contributions of the Computer to Instruction

The literature on this subject deals with a larger list of users which for purposes of this paper I have condensed to three: student, teacher, and author. I will mention two or three factors which seem important for each of these.

The student should benefit from a prompt evaluation or self-check of his response. Automated feedback is important wherever it is difficult for him to judge whether his response is correct. The problem of self-confirmation is apparent in some programed instruction texts when the right answer is a complicated expression with a number of equivalent forms. Another factor which can promote student learning is the availability of records and a summary of his performance for his own use in planning further study; this also serves to reward his successful achievements. Finally, the student may benefit from instruction strategies more complex than could be managed in a booklet format. If, for example, the computer is wired and programed to control visual displays, the lesson designer can be sure that the student has before him the right segment of text at any time in a complicated remedial sequence.

The teacher benefits more directly than the student from the ability of the computer to record and summarize records. The teacher can have the performance scores and a record of the time each student has spent with each exercise which he can have much greater confidence in than is possible with self-instruction texts used in a less controlled environment. Therefore computer-based instruction often can serve a secondary purpose of examination, especially for diagnosis of learning difficulties. Finally the teacher has the opportunity (at least in some computer systems) to adapt the curriculum for a particular class or individual student more readily than is possible with most printed formats for learning materials.

The author of the learning exercises benefits from records and summarization, perhaps more than the student and teacher. The designer has responsibility for evaluating, revising and further testing and revision of the instructional materials. The control given by the computer system provides a further aid to determining just where the materials need revision. The computer system could also provide some clerical and bookkeeping aid during this revision although this is not a part of most systems at present.

Constraints of Programing Languages

Now I can move to the core of my presentation: a consideration of computer languages for programing learning exercises in mathematics. I recommend a broad perspective on uses of computers in mathematics education, looking beyond COURSEWRITER and the Stanford drill strategy.

At a national computer conference recently I discussed three or four kinds of programing languages (Zinn, 1968*b*). Some classification is desirable because there are over 30 different languages and dialects which have been developed especially for instructional use of computers, and the differences among them are not very great in most comparisons.

I shall briefly describe the four classes of languages, depending on examples to make clear the useful distinctions: (1) simple notation or data format; (2) frame-oriented testing or instruction; (3) task-oriented notation; and (4) procedure-oriented languages. You will see that the lines of division are not clear, but I believe the classification can simplify a topic which has been made unnecessarily complicated by lack of communication among those working on the problem.

1. Simple notation or data format

The most straightforward approach to serving the needs of an author may be to provide a format into which he places elements of the curriculum. For a long while the PLATO System developed by Don Bitzer and others at the University of Illinois has provided a "tutorial logic" into which the author simply places the questions, answers, and hints to be delivered to the student in sequence. Because of the convenience of the video terminal on the PLATO system, each question and corresponding hint is placed in the appropriate location on a large sheet of transparencies to be inserted in a scanner. The computer program successively presents the question frames, provides a hint when the student asks for it, provides the right answer when needed, and records performance data for later inspection by the author of the exercise.

A program (or data set) is characterized in Figure 1 in only one of many ways it might be written. You have seen in popular literature many examples of the appearance of such an exercise to a student; I have not included one here.

		Questions	Hints	Answers
Instruction Sequence	1	$2^3 = ?$	$2^3 = 2 \times 2 \times 2$	8
	2	$3^2 = ?$	$3^2 = 3 \times 3$	9

FIG. 1—From a simple program (data set)

2. Frame-oriented testing or instruction

IBM'S COURSEWRITER is the best known example of this kind of language, especially the original version for the IBM 1401. It grew out of a statistics course authored by Ralph Grubb in W. R.

Uttal's CAI project (Uttal, 1962) using an IBM 650 at Watson Research Center during the early 1960's. Lenore Selfridge had been coding Grubb's CAI course frame-by-frame (according to the logic he defined) and suggested a Teacher Interpretive Program (TIP) to simplify the task of entry and revision of the statistics program. Other authors at Watson Research Center at the time were using other instruction strategies, each programed individually.

The advantage of using TIP was sufficient to induce other authors to use the same approach—a kind of computerized programed instruction—and a language called COURSEWRITER achieved status as a general language. Many languages very similar to COURSEWRITER have appeared, some of them developed independently. However, they are useful for only this one type of computer use; programing other instruction strategies requires additions to the language and special efforts of a coder.

A sample program which extends somewhat the previous example is shown in Figure 2; statements in brackets anticipate certain

```
qu 1.  $2^3$ = ?                                   Counters:
   ca 8                                             c2  number correct
        ty  correct                                 c3  number of hints
        ad  1//c2                                   c4  number of answers
   wa 6                                           Switches:
        ty  No. Did you read it as:  2 × 3 ?        c7  if multiplied
            Watch for exponents.
        ld  1//s7
   un $2^3$ = 2 × 2 × 2
        ad  1//c3
   un The answer is 8
        ad  1//c4
qu 2.  $3^2$ = ?
   ca 9
        ty  correct
        ad  1//c2
   wa 8
        ty  No. Did you read it as:  $2^3$ ?
            Watch the order.
   wa 6
        ty  No. Did you read it as:  3 × 2 ?
            Watch for exponents.
        br  ×10//s7//0
        ty  You made this error on the last problem too?
   un $3^2$ = 3 × 3
        ad  1//c3
   un The answer is 9
        ad  1//c4
```

FIG. 2—From a frame-oriented program

wrong answers, and note the second occurrence of one kind of error. Otherwise, the similarity of the code and conversation to a programed text is apparent. In fact, translators have been written to accept linear (or simple branching) programed text and derive CAI interaction with a student.

3. Task-oriented notation

Whenever one or more authors have a singular instruction task, determined in part by content and in part by instruction strategy, a special language or dialect may be useful. PLANIT is particularly suited to tutorial and problem solving in statistics; in fact, it was designed especially for a curriculum development project (Rosenbaum, Feingold, Frye & Bennik, 1967) and only later came to be used in other areas. Those aspects concerned with data generation and computation should be obvious.

An example is given in Figure 3 of part of a mystery problem coded in a notation similar to the MENTOR language which was developed at Bolt Baranek and Newman (BBN) especially for "socratic dialogues." Initially BBN was working on the training of

```
GENERAL  "Proceed with investigation."
       ACCEPT
             IF /suspects/
                   1) "Wife, brother and partner."
                   2) "No new suspects."
             IF /lab, rifle, glass, pipe/
                   IF ALL REP, TO LAB
                   "I advise you to check reports first."
             IF /interrogate/
                   IF ALL LAB, TO INTERR
                   "I advise you request lab tests first."
             . . .
             . . .
             . . .
             "I don't understand."
LAB  "This is the lab."
             IF /glass/
                   IF WIFE
                        "Glass contained arsenic."
                   1) "Prints belong to the wife."
                   2) "Nothing new."
             . . .
             . . .
             "What is it you want?"
             ACCEPT
             TO LAB + 1
```

FIG. 3—Sample of a notation suited for exercises in decision making

skills such as information gathering and decision making needed in medical diagnosis or electronic trouble shooting. Considerable convenience was gained by providing for the "stacking" of replies so that #1 is used the first time, #2 the second, etc. Also the sequencing statements appear very much like logical expressions.

4. Procedure-oriented languages

All of the languages or notations in the first three categories had to be programed for the computer in a regular computer language which could be interpreted by the machine. Any of these languages could have been used directly, but some are especially convenient for writing procedures for interactive use on a computer, or for conversational instruction in particular. One such language is CATO for the PLATO System at the University of Illinois. The tutorial procedure was described earlier; many other logics (or procedures or strategies) have been written for the PLATO System, including one called TUTOR which looks somewhat like COURSEWRITER.

Another language for writing procedures is RCA's Instructional System Language (ISL-1) adapted from Stanford's Teacher Student Algol (TSA). The major use so far has been to represent the procedures for mathematics and language drills in the Stanford project. In fact the RCA instructional systems operated for the New York City Schools and the Waterford Schools in Michigan have been particularly arranged for economical math drills for large numbers of students. I will not go into the details here; you can see in Figure 4 that such languages are for programers to use in describing procedures.

Which kinds of languages have been most used? And what about misuse? More languages and dialects fall in category two than any other, and probably more author hours have been invested in the computerization of programed instruction text than other instruction modes. The "data formats" and "task-oriented notations" have been used extensively at installations that have those language facilities.

Increased use of procedure-statements and (separate) curriculum files will be beneficial for the field, and increasing use of computers in large curriculum development projects will require this approach for economy. I must say again that languages of this fourth type really are for computer programers and for educational technologists specializing in computer applications; these persons should produce the user-oriented languages or data formats which maximize convenience of the curriculum expert.

Some data formats may take on special and interesting characteristics: the curriculum design team can represent the intended knowledge and skills in some kind of structure which both they and the computer can interpret; and specialized computer programs will try, through various means built in by specialists in learning and information systems, to see that each student achieves those objectives. Professor Uttal describes the goals and present status of his project on generation of instruction and diagnosis for analytic geometry.

Perhaps because of its availability, COURSEWRITER has been used to do many different tasks, including conversational computing, simulation, information retrieval, and problem solving. In part this is a credit to those who have extended the language, but mostly it is a result of the ingenuity and unlimited vision of its users. These

```
        For I = 1 TO N UNLESS ERRORS  5
          BEGIN
          HINT = 0
NEW       ERASE
QUES      DISPLAY QUES(I)
          ACCEPT UNTIL TIME  20
              BEGIN
              IF RESP = ANS(I)
                  TYPE "Correct"
                  INCREMENT I
              ERRORS = ERRORS + 1
              IF HINT = 0
                  DISPLAY HINT(I)
                  HINT = 1
                  TO QUES
              DISPLAY "The answer is" ANS(I)
              INCREMENT I
              END
          IF TIME UP = 0
              DISPLAY "Time is up; try again."
              TIME UP = 1
              TO NEW
          DISPLAY "Time is up."
          DISPLAY-PROCTOR "Too much time." STUDENT, LESSON
          TO HELP
          END
        IF I = N, TO NEXT
        DISPLAY-PROCTOR "Too many errors." STUDENT, LESSON, I,
            ERRORS
HELP DISPLAY "You seem to need help. Ask "ON-DUTY" for assistance."
        PAUSE
```

FIG. 4—From a program stating a drill procedure for the data set in Figure 1

diverse applications are difficult to code and check out, and costly to run.

The differences among these languages have definite implications for the operation of a project. For example, those involved in operational uses of computers for math instruction in the schools should not pay for computer time and equipment that is not part of the immediate task. It is easy for a system designer to build up considerable overhead while he adds flexibility and various optional features. An operational project in the schools must achieve some degree of success as measured by student learning and acceptance by the school staff, and with the lowest possible investment. It is very important that the system be reliable and usable, but it also must remain within reasonable economic bounds.

In contrast, a project working on development of system features and language characteristics should invest in flexibility. Furthermore, the curriculum writers who choose to work with such a project are willing to give up some convenience for the sake of experimentation. They have to learn new language features frequently, modify or discard programs which used outdated procedures, accept errors and unreliability in the system, etc.

Staff on a curriculum development project are as concerned about economics, reliability, and useability as those associated with an operational project in the schools. However, it becomes important to provide convenience and low error rate for the author writing and the student testing the material. This is not the same as economy and convenience for the student who eventually will use materials day-to-day in the schools; within a suitable curriculum development environment the terminals may be more expensive, the speed of compilation of new materials more rapid, priority given to revision of materials, etc.

A project which is primarily concerned with research on mathematics teaching and learning will require flexibility in specifying instruction strategies, capability to record and analyze detailed data, etc.

Summary

I have not attempted to talk about CAI curriculum in mathematics, nor to survey the work of others in any detail, although I suggest that this conference should initiate some useful survey and information exchange activity.

There are three main points I have tried to put forward to those working on projects now or considering such activity:

1. Look around at what else is being done or might be done.

2. Assess potentials of computer use (and misuse) in reference to your own goals, sub-goals and immediate needs.
3. Engage in reasonable projects, whether operational, developmental or research, according to appropriate criteria.

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Reaction Paper

RICHARD V. ANDREE
Chairman, Department of Mathematics
University of Oklahoma

(The remarks to follow were written in reaction to the original papers presented by Duncan Hansen and Karl Zinn on CAI Software Development.)

Many reactions to today's various talks run through my mind; a few may merit our combined attention. We are discussing primarily, I think, computer-assisted instruction in mathematics. I know of two college-level computer-assisted instruction projects in mathematics that did not involve a single mathematician anywhere. I am not sure if that is good or bad, but it's true. I was therefore very pleased when I looked over the material which Dr. Hansen presented to see that the project in college physics did involve physicists. I noted that in the thirteen-item budget for the college physics program the only budget item that was lower than the amount spent for physicists was that spent for proctors. Film art work received the same amount as did the physicists, and everybody else got more. Possibly that is not really important. I suspect it very possibly may be the right thing to do, but it is interesting that less than 3 percent of the total budget of a curriculum development project in college physics was invested in physicists.

We have just heard two very carefully prepared and highly interesting papers. I enjoyed them both. I could sit here and nod my head "yes" at almost every point that the speakers made. Somehow it all seemed familiar and comfortable and noncontroversial. Yet you and I both know that the computer-assisted instruction is actually a highly controversial subject in many educational circuits. Professor Hansen mentioned that the complexities of CAI course development far transcend that of preparing a conventional textbook. Having written conventional textbooks, and programed instruction and computer-assisted instruction, I can agree most wholeheartedly with him. However, as I read his eight points I could not help but note that each of these points was identical, or at least very closely related to points with which the author of a conventional textbook must also cope. "Clarity of curriculum objectives" is desirable in either case, as are "varieties of problem responses." You can go down the list and as you do you discover that these points do not just occur in computer-assisted instruction. They occur everywhere. According to Professor Hansen's paper, the problems of CAI seem to be very similar to those encountered in writing a good conventional text. And yet, I cannot help but feel that computer-assisted instruction has much to offer mathematics that the conventional text does not offer, if only we were bright enough to figure out what it is. One of the important advantages of computer-assisted instruction was pointed out by Professor Zinn.

Back in the early 1960's (and that's ancient history in the computer world), the University of Oklahoma had a computer-assisted instruction teaching system using our old 650 computer. One of its primary features was the rather complete student records and item response analyses that were stored on the 650 discs that could be recalled either in detail or in summary on a day-by-day basis and also on a cumulative basis by the author who was also the instructor. This led to continual revision, and we hope improvement of the textual material. It does not matter whether you happen to call this educational research or experimental textbook writing or author assistance or what, the end product was increased knowledge of how to teach and often increased examination of what to teach. Eventually this *can* result in better teaching. It doesn't have to, but it can. Perhaps this is an important contribution of CAI.

My next point is that it seems to me that in the conventional classroom with a conventional teacher, the role of the teacher and the role of the textbook are rather different. We all know of cases in which an excellent teacher has done a good job of teaching mathematics to students without any notes and without any textbook. We can find lots of examples in which students have learned by using a textbook without any teacher, sometimes in spite of the teacher, but I still basically feel that the teacher's role and the textbook's role are often quite different in the student's learning experience. Each supplements, but does not replace the other. As chairman of a mathematics department I must admit that I do not have too much faith in a teacher who merely reiterates what the textbook says, often with less accuracy. Similarly I am not much impressed with a computer-assisted instruction program that merely turns the pages of an ordinary programed text, be it of Skinner or Crowder type. Possibly we do not yet know what facets of mathematical learning computer-assisted instruction is supposed to replace or supplement or augment or whatever it is that CAI does.

Perhaps Professor Greenberg is correct in suggesting that diagnostic testing may be a very important contribution of computer-assisted instruction in the field of mathematics. Perhaps, as Professor Zinn hints, one important role may be in simulation. Perhaps its really important role is going to turn out to be in educational research or in assisting authors. I do not know, but I am pretty much convinced that computer-assisted instruction is going to have much the same dull fate in mathematics that instructional films in mathematics have had unless we have a very careful analysis of its advantages in the instructional process so far as mathematics is concerned. Are there specific concepts in mathematics which are better taught by use of computer-assisted instruction? I think the answer is yes, but I do not know. By "better" I mean that either the student learns better or the student learns at the same rate, but it is cheaper to do. I will accept either of these criterions as better. We ought to use computer-assisted instruction to supplement other mathematical teaching techniques in those areas in which it is a superior tool, but I do not think we ought to expect CAI to do the entire job. This is one of the basic errors that was made in the use of educational films. It has only been within the last two years that people have started to analyze just what a mathematics film may be able to do as well or better than a teacher. In teaching physics you do not have this problem. In physics it is obvious what you are going to do. You are going to set up an experiment and you are going to film the experiment. Then you show the film of the experiment to the student and you do not have to repeat the work. Thus students can partake in experiments too dangerous or too costly or too time-consuming to be performed on an individual basis. Mathematics is not done by conducting experiments, but we waited almost thirty years to analyze what contributions film can make to mathematics education other than filming lectures. I see no reason why computer-assisted instruction needs to wait thirty years before it undertakes a similar analysis.

Perhaps this is part of the research which our esteemed speakers are urging us to undertake. If it is, I hope we will pay them heed.

As I listened to our speakers I got the feeling that they are thinking of using computer-assisted instruction primarily in *beginning* work in mathematics. By "beginning work" I mean from elementary school up through college sophomore level. Yet it seems to me that one of the most vital uses of computer-assisted instruction may well be at the advanced graduate level in mathematics. Graduate students and graduate professors very much need quietly, unobtrusively without outside publicity, to be able to brush up on half-remembered concepts from outside their particular specialty as well as exploring new areas. Instruction at this level is very difficult to obtain and is expensive. Quite possibly we should investigate computer-assisted instruction at this level where the dollar pay-off per user is high, even though we do not have so many users.

I hesitate to do so, but I have a real quarrel with the basic philosophies of some of our speakers. As a guest I should probably be agreeable and shut up. However, I believe that in a closed family group like this, it is perfectly reasonable to air controversy and honest differences of opinions and that it may even prove a catalyst for eventual improvement. I would like to bait you a little bit by challenging one of our basic hidden assumptions that has come up four times, by count, today. Namely, I have considerable difficulty in justifying the recent emphasis not only here but everywhere on *behavioral* objectives for a mathematics course. I believe that objectives possibly expressed in behavioral terms are desirable in writing a mathematics textbook, but I seriously question the desirability of having firm advance objectives, whether behavioral or not, in *teaching* many mathematics courses. I know that is heresy.

A serious teacher always has some rather loosely-formed objectives for his course, but as a departmental chairman I have found that some of our best courses are given by professors whose objectives for a given course are constantly vacillating, not only from year to year, but from week to week. The objectives of a course may well be a function of the current student response and what the teacher happened to be reading last night in a mathematical journal and a lot of other facts. This makes it very, very difficult for chairmen and administrators. It is even harder on the committee that sets examinations for these students when a teacher varies the nature or the goal of a course to meet current student needs, but I really think it may be good for the student. In my own institution I have some hope that eventually we may be able to use computer-assisted instruction to present a certain hard core of theory and skill in mathematics (if such a core can be found) and be able to encourage our teachers to vary their objectives and methods and techniques in any way they feel will suit their current opinion of what the objective ought to be. I strongly suspect that the nicely-stated objectives of many mathematics courses (CAI or conventional) are determined *after* the course material is completed. In short, I am not convinced that course objectives of any type, let alone behavioral objectives, should be determined *in advance* in a fixed form for a mathematics course. I think objectives should be *discussed* at great length, but should not be determined. I invite you to disagree with me. In this way we may reach a better understanding of our own objectives.

Reaction Paper

WILLIAM R. UTTAL
Professor of Psychology, University of Michigan

(The remarks to follow were written in reaction to the original papers presented by Duncan Hansen and Karl Zinn on CAI Software Development.)

The two papers we have just heard have helped us to acquire a working knowledge of the current status of software development in computer-based teaching systems. Each of the two papers has a theme which I would like to extract from the context in which it has been placed. After some brief comments on their themes, I would like to develop a theme of my own and hope that the chord which sounds from the three of us clearly defines the potential contribution of the computer to the teaching of mathematics.

First, let's consider Dr. Hansen's paper. A main point which he makes is that up until now it has simply been impossible to seduce college professors into sitting down at a computer terminal to dictate the necessary dialogue to the computer. Let us consider why this is so. Essentially, we are asking a teacher to anticipate all of the conversational dialogue which he more ordinarily creates as needed in his classroom or conversation, before it is actually needed. This is, at best, a dull and dreary task. If one combines this with the constraints of one of the currently available programing languages, it is no surprise that little programed material of quality for computers has been forthcoming from this source. The creative or generative act of typing up the dictionary of comments and dialogue items, simply is not the same sort of thing as writing a book, no matter how seductive the argument may be.

It appears to me that the notion of university professors pounding out the tons of material so that corporations can sell their hardware was, from its inception, simply an ill-founded idea conjured up by some particularly insensitive and unimaginative administrator who thought he could "hire" the brains needed in the same way he might have hired draftsmen or assembly line workers. As most of you know, the cultural structure of a university simply does not permit such a scheme to work.

The result has been that in many cases the dreary work has been done by graduate students and hired technicians working in conjunction with some of the less interesting bookkeeping type of teaching machine compiler languages. Thus we see that influential workers in the field, such as Dr. Hansen, seem to have turned away from substantive content matter as their main interest to an interest in the system and management procedures necessary to provide routine guidelines for routine technical programers. But, while Dr. Hansen has clearly defined the nature of the programing bottleneck, I do not believe that he has proposed a solution by simply suggesting better management techniques. We may be more in need of innovation than organization.

Earlier in his paper, Dr. Hansen had discussed a number of factors which can influence the rate of development of programed materials. Although we all would agree with him that this is a complex field and all of these factors as well as a number of other less tangible ones, do influence the speed of curriculum material development with present techniques, I feel impelled to express my disagreement with the implied notion that computers are applicable only with difficulty to the teaching of mathematics. As I hope I can show you below, innovation in technique and logic is still possible and often not too terribly difficult to implement.

I certainly wish that Dr. Hansen had spent more time telling us about the specific accomplishments his laboratory may have achieved in software development. We all would have been particularly interested in the tutorial logic of the courses he developed and details of the teaching strategies allowed with whatever compiling language he used.

Let's now turn to Dr. Zinn's paper. Dr. Zinn has, in his usual insightful way, organized the field and emphasized the different modes of computer-assisted instruction. I believe that the real essence of his presentation was the categorization of the different classes of Computer Teaching Machine Compilers. He distinguished four separate classes:

1. Simple data formatting languages
2. Frame oriented testing and instruction languages

3. Problem oriented languages
4. Procedure oriented languages

One might take issue with the specific categories presented, but the general notion of a classification system is correct. To be a little more specific, however, one can identify a thread which passes through all of these compiling languages which makes it possible to make the separate categories into steps along a continuum. That thread is the degree to which the language performs the creative functions we now ask of our authors. In other words, as we progress through his outline, we notice that an increasing amount of automatic generation of tutorial material has been built into each of the programing systems. We see in Dr. Zinn's classification system, an evolution in the systems from those modelling routine administrative assistants, to those modelling a colleague who can generate specific tutorial dialogue material. The older, more primitive systems of the first two categories could only acquire an answer, compare it to a table of prestored possible answers, and then select an appropriate next message. These are examples of programing systems which I like to call *selective*. The other two types of languages, to a degree, contain some capability for actually creating tutorial materials. I would call those types *generative* compilers. This is the trend—the evolutionary trend which I see very clearly displayed by the order in which these categories have been presented.

As an aside, I might tell you that I also, unfortunately, observe the existence of a third type of computer teaching machine, which is neither selective nor generative. This category is one which includes those gadgets some have referred to as *degenerative* computer teaching machines. They are characterized by simple multiple choice response capabilities and a microfilm type of block information presentation. These machines certainly reflect a complete lack of awareness of the real capabilities of the computer as a teaching tool, and add great strength to the notion that *"not all teaching machines which use computers are computer teaching machines."* I imagine it was this sort of device to which B. F. Skinner (1968) was referring in the somewhat intemperate and apparently unknowledgeable outburst recently quoted in *Forbes* magazine.

I would like now to discuss what I consider to be the critical feature distinguishing the older selective computer teaching machines and the newer generative ones that some of us are now beginning to work with. In essence, I do not believe that the human tutor operates in the fashion of a table scanning device—i.e., he is not a dictionary user. Rather, he is an analyzer and generator who determines what the needs are, and then from some general set of rules or heuristics formulates a sentence, a problem, a diagnostic, or a remedial unit. The best possible model we could use for the development of a computer tutorial situation is exactly this—the human tutor. Up until now the model of computer tutoring has been, in general, the dictionary or its descendant, the programed text. I would now like to tell you about some of the experiences we have had in our attempts to program a purely generative computer teaching machine, so that it behaves like a tutor, and not like a telephone directory. It is our intent to determine how far we can go in using a library of algorithms to take over the generative role played by the human tutor who otherwise would have spent those tedious hours sitting at the author's console in the older CAI environments.

Before I begin, however, I should point out that while the computer is, in some mathematical sense, theoretically capable of presenting or handling almost any concept, there are practical limits to what can be generated. I am sure that most of you would agree with me that generation of a generalized verbal dialogue would be extremely difficult for any of the current day computers to accomplish. The application of generative techniques is feasible for the moment, only in those bodies of knowledge in which the logic of the involved language is precise enough, formalized enough, and sufficiently ordered. Obviously, the most appropriate types of material are mathematics, chemistry, and logic. For our project we have chosen a small segment of the first year college mathematics course—analytical geometry. We have chosen this curriculum chunk primarily because it is a small self-contained unit of knowledge, but also because the algorithms we are developing promise to have wide general applicability to other forms of mathematics teaching. Also important in our decision was the fact that analytical geometry is essentially the interface between high school and college, and it seemed to me that if we were successful, our contribution at this level would be most worthwhile. I should also point out again, that this curriculum chunk is but a vehicle. We are not really interested in analytical geometry per se, but rather, in the generative algorithms which we are developing.

The general approach has been to consider a model in which the separate components of the tutorial process are distinguished from each other. One afternoon I made up a very rough sketch of what I thought a human tutor does. This is presented in Figure 1. This preliminary sketch has gradually evolved during the course of the last few months into the plan of our research project. With the

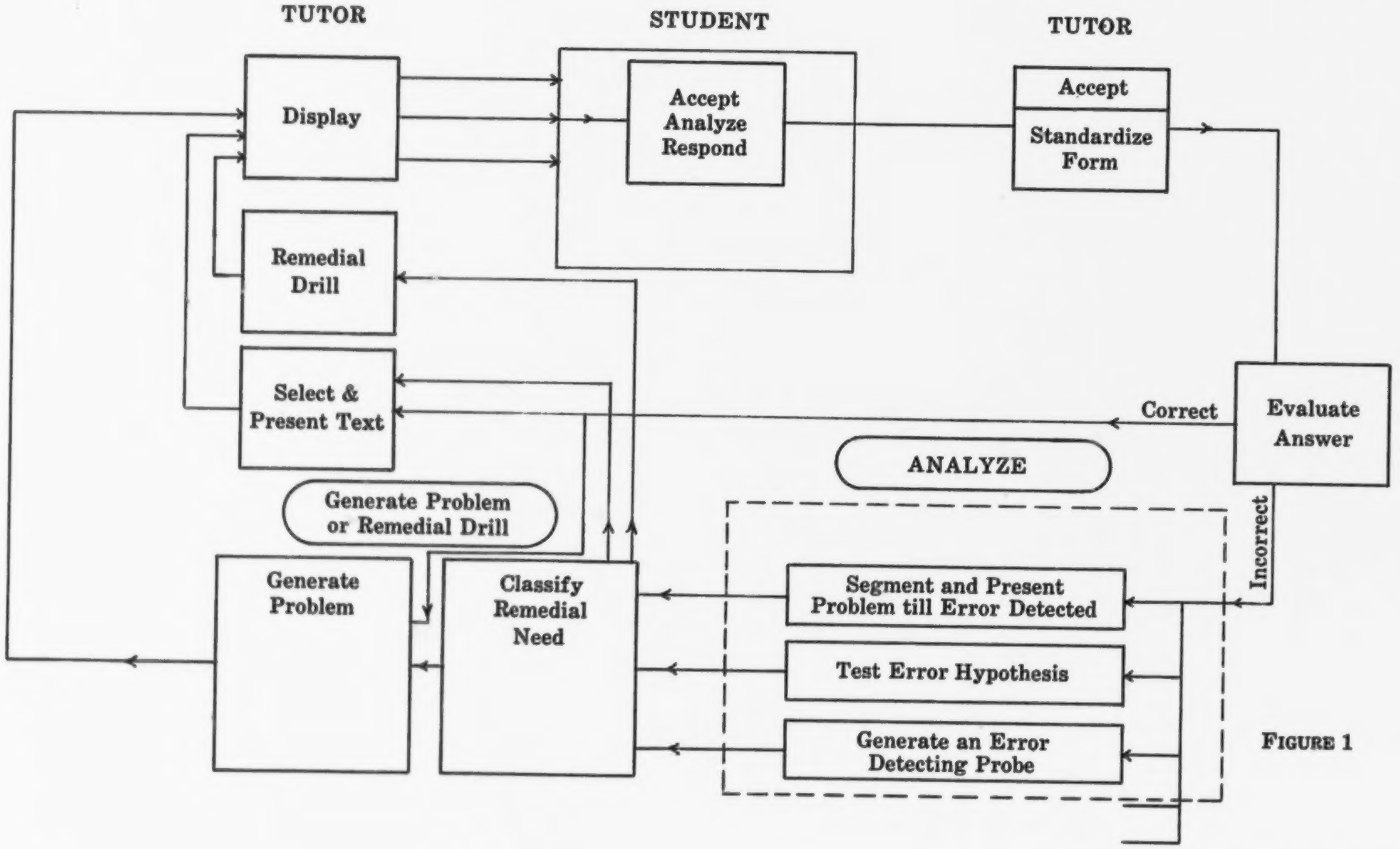

TUTOR
STUDENT
TUTOR
Display
Accept
Analyze
Respond
Accept
Standardize
Form
Remedial
Drill
Select &
Present Text
Correct
Evaluate
Answer
ANALYZE
Incorrect
Generate Problem
or Remedial Drill
Generate
Problem
Classify
Remedial
Need
Segment and Present
Problem till Error Detected
Test Error Hypothesis
Generate an Error
Detecting Probe

FIGURE 1

understanding that it is not static or final, and certainly not complete, I present our current project plan to you in Figure 2. Although this outline is presented as a flow chart, I do want to point out that the sequence of flow is not quite so smooth, and the executive may call specific functions well out of the order indicated. The general strategy which we have followed is to assume that each of these separate functions can be accomplished by a small group of subroutines, each of which can individually be called by a supervisory executive program. Our major effort and progress so far has been in the development of the family of subroutines. In each case, to test them out, we have written a miniature executive routine of no great complexity. During the next few months we will be developing the master executive which will contain the decision rules necessary to sequence appropriately the student through the family of subroutines.

Although the specific nature of the hardware we are using is unimportant, it may interest some of you to know that all of this work has been carried out on a Digital Equipment Corporation PDP-9 with some additional magnetic tape storage. Magnetic tapes, as is well known, are not adequate for this sort of random access application because of their long access time, and we imagine that a disc system will be required at some future time for a complete realistic demonstration. No attempt at time-sharing has been made. We are exploring the logic of the generative process and did not want to concern ourselves with the complex housekeeping problems involved in multiple student operation. Our one tutorial station is a Computer Communications Incorporated CC-301 Television display with both alphanumeric and graphic capabilities.

I would like to spend the rest of the brief time that I have been allotted, to tell you about some of the routines we have developed. Some of them may impress you as being trivial and others may seem to be substantial accomplishments. (You may be wrong on both counts!) In each case, I ask that you imagine how these subroutines would fit together at some later time when our executive is able to call them up in a usable sequence. The progress I report to you today does not, I repeat, include this degree of synthesis.

Before I start this discussion of the specific subroutines, I do want to express my appreciation to three people who have carried the bulk of the responsibility for the development of the individual algorithms. Pvt. Timothy Pasich is now with the United States Army, but Mrs. Miriam Rogers and Mrs. Ramelle Hieronymous are still with us. (There are several different messages in that brief sentence, believe me!!)

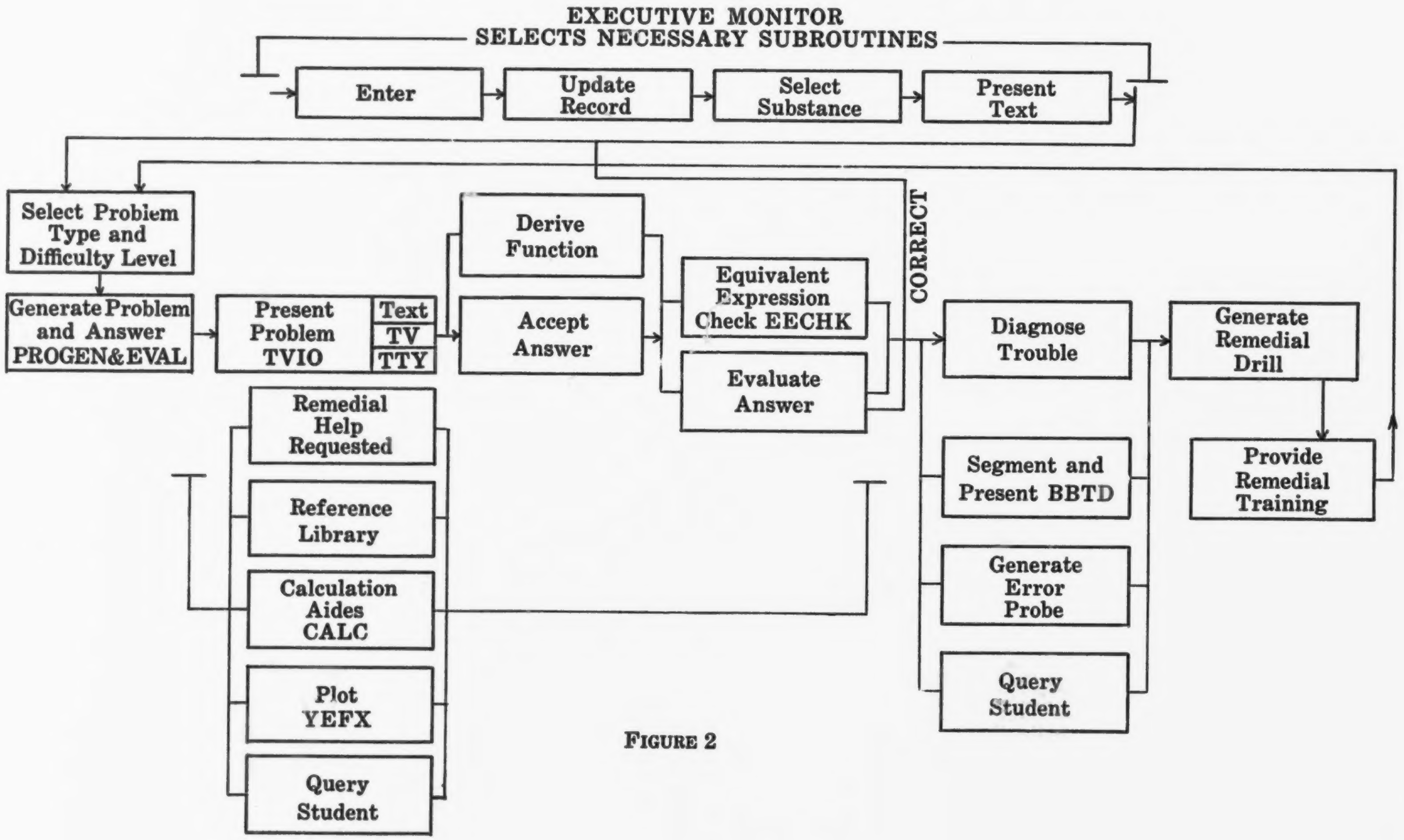

EXECUTIVE MONITOR
SELECTS NECESSARY SUBROUTINES
Enter
Update Record
Select Substance
Present Text
Select Problem Type and Difficulty Level
Generate Problem and Answer PROGEN&EVAL
Present Problem TVIO
Text
TV
TTY
Derive Function
Accept Answer
Equivalent Expression Check EECHK
Evaluate Answer
CORRECT
Diagnose Trouble
Generate Remedial Drill
Provide Remedial Training
Segment and Present BBTD
Generate Error Probe
Query Student
Remedial Help Requested
Reference Library
Calculation Aides CALC
Plot YEFX
Query Student

FIGURE 2

Problem Generation (PROGEN)

At the present time we have several independent problem generation routines and we expect ultimately to have many more. As one example, we have a routine which is capable of generating any of the standard two-dimensional analytical forms (straight lines and conic sections.) This routine produces as its output, algebraic expressions which can be used in a number of ways, by substituting values in the standard quadratic formula ($AX^2 + BY^2 + CX + DY + E = 0$) representing the family of two-dimensional forms of analytical geometry. The subroutine performs its function by substituting random numbers for certain coefficients and allowing certain other coefficients to go to zero, depending upon the desired geometrical form. For example, to provide an analytic equation for a circle at the origin of the axes, for use in some problem, the subroutine sets C and D to zero, and substitutes random numbers selected to meet certain conditions for A, B, and E. As another example, another problem generation routine produces a question which asks whether a certain point (x,y) falls on the locus of the points so generated by the equation generator. The values of X and Y are also generated by random number techniques and are presented to the student in conjunction with the equation generated by the routine described above.

Answer Generation (EVAL)

A related program substitutes the values of a given x and y coordinate into any algebraic equation and determines whether or not the equation is satisfied. This general purpose routine can also be used in conjunction with the problem generation routines described above to generate automatically the answer to a problem which has been asked of the student. For example, to determine if the randomly generated point x,y falls on the locus represented by the equation also created by our problem generation routines, it is necessary to carry out the substitutions and arithmetic. This is done by the subroutine just described. EVAL is also used as a subroutine in the calculator we mention later.

Equivalent Expression Checker (EECHK)

To determine the equivalence of two algebraic formulae in a general way is a very difficult task. I have been advised by some of my mathematical friends that an algorithm to do this has not yet been developed in a rigorous formal fashion. However, the teaching procedure which we are using is not a rigorous and formal procedure. Therefore, we have been able to develop a subroutine which can successfully (hopefully) distinguish between equivalent and nonequivalent forms over 90 percent of the time. I am sure that it can be fooled, but infrequently enough so that no serious damage will be done in our tutorial environment.

EECHK declares two expressions algebraically equivalent if the two functions are numerically equal for two different randomly selected sets of values for the variable. It evaluates the functions in the following manner: For each symbol in the symbol table EECHK randomly generates a value between −5 and 5 (integer) and then using the answer-generating routine described above, determines if the numerical difference between the two functions is less than some arbitrarily small number. If it isn't, EECHK declares the two expressions to be nonequivalent. If it is, EECHK generates a second set of random values and again determines if the numerical difference is less than that small number. If it is, EECHK declares the two expressions to be equivalent. (EECHK also determines if an expression is equivalent to the negative of the other by changing the sign of the value of one of the functions before testing for numerical equality.) Subsequent experience will tell us whether the dual check is sufficient or whether it is necessary to use a more thorough testing procedure. Some routine checks for trivial cases have also been built into EECHK, and other checks are found in the mathematical subroutines which are called by EECHK itself.

EECHK and advanced versions of it will allow us to track a student step-by-step, through a literal derivation, determining at each step whether his algebra has been correct. This should prove to be extremely important. It will also allow us to determine if the answer to a question requiring the student to respond with an algebraic expression is acceptable. Although there exist standard forms for all analytical geometrical expressions, not all answers should be expected to be in the standard form, and EECHK will allow us to accept unstandardized, yet correct answers.

Binary Branching Tree Partitioner (BBTP)

One of our first diagnostic tools capable of generating dialogue is the *Binary Branching Tree Partitioner* (BBTP). This program takes an algebraic expression (not an equation) and dissects it into subexpressions. The subexpressions are presented to the student. If he does not give a correct answer, the subexpressions themselves may be further divided into even lower level subexpressions by the program, until the dissection has run down to single operations.

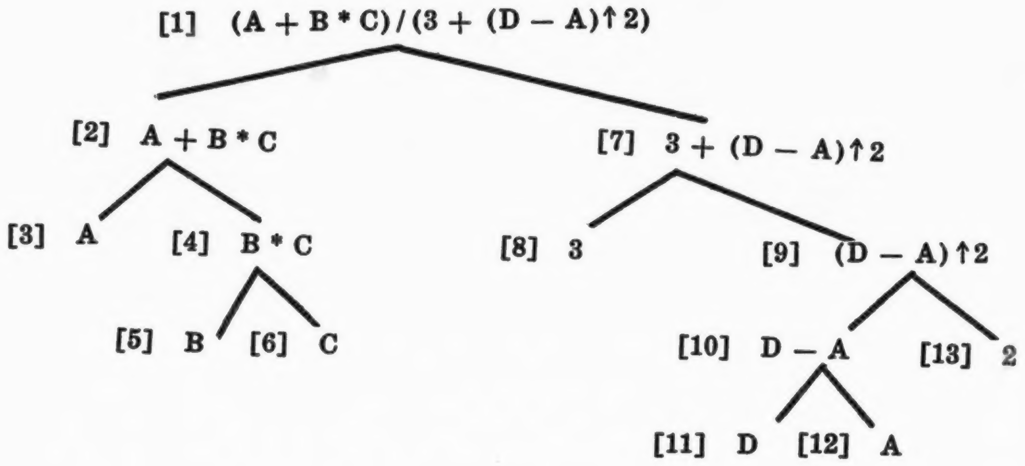


FIGURE 3

At any time that the student provides a correct answer, BBTP starts reassembling the subexpressions back into the form of the original expression in sequential ascending steps. If the student makes a second error at any stage, the partitioner will start down the tree again.

BBTP is able to spot specific deficiencies and guide the student step-by-step through the evaluation of a specific formula. It is, we believe, however, only the first of a necessary family of diagnostic routines which will handle the general problems of error detection and correction. Figure 3 shows the type of branching and partitioning which is applied to a sample algebraic expression.

The important fact is that BBTP is a general algorithm which can perform this same function for all algebraic expressions and thus represents the equivalent of an enormous amount of preprogramed material. In this sense the notion of the cost of an hour of instruction becomes irrelevant in this generative context. A generative algorithm can rapidly make the cost per hour of student drill or tutoring vanishingly small.

Appendix 1, attached to this note, is a sample program which shows some of the generative routines we have discussed. A general class of problems is defined in plate 0. R_1 through R_5 are random variables. The limits within which we will allow them to vary are also indicated. $\underline{X =}$ is the standard format of the expression with which we want the student to work. The second and third frames simply show the problem presentation format displayed on the face of the television. From frame 4 on a new problem, algorithmically generated by substituting random variables in the expression, is presented to the student. We see that after a mistake is made, the expression is dissected under control of the

Binary Branching Tree Partitioner. In this particular problem, the student was able to recover without remedial help. In the example shown from frame 17 on, however, the student could not recover and bottomed at the foot of a branching dissection. In this case the program identified the error and directed him to call his instructor. At some future time we hope to have remedial routines which will automatically take over in such a situation. Starting in frame 24, a similar situation obtains.

Utility Routines (CALC and PLOT)

In addition to those generative routines which are specifically tutorial, we have already also provided our prospective students with two useful and equally generative utility functions. The first is a routine which will take any algebraic expression and plot its equivalent graphical form on our television display. Students are thus able to manipulate the constants in a given expression and observe the effects on the geometry of the situation.

The second utility function is a powerful calculation aide which includes algorithmic evaluation of trigonometric and logarithmic functions. The student can ask, for example, for the value of the cosine of a given angle and then use that number to evaluate an expression. We have intentionally not made it possible for the student to short circuit the learning experience intended in the problem presented. Rather, his calculation aide is limited to arithmetic evaluation of expressions which he must construct in a way different from the manner in which problems are presented to him.

Conclusion

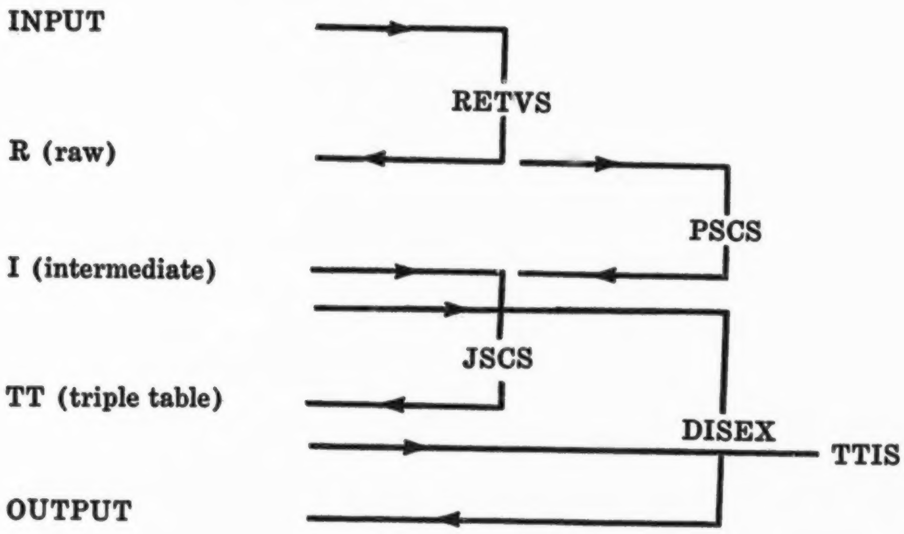
This, then, is a brief introduction to the sort of algorithmic generating procedures which we are developing. I also would like to add two final comments. First, in addition to the specific routines to perform the tutorial functions, we have also had to develop a family of system routines to perform various functions. Some of these perform the typical dirty work of binary to decimal and decimal to binary conversion functions and related housekeeping tasks. Others, however, are very specific to the information handling system which we have been developing to meet the needs of a computer tutorial system. Our system includes a set of string-handling techniques by which data (expressions and equations) can be stored in several different formats, depending upon the nature of their intended use. Table 1 lists the names of some of the routines and format converters which I would be happy to explain after this talk, to any of you who are especially interested.

TABLE I

Housekeeping and Utility Routines

BCDBN
BNBCD
NCHK
OCHK et al
RANDOM
RIBEL
RIN et al
SCHK et al
TTIS
TVIO (TIOP)

FORMAT MANIPULATION



Finally, I hope that the main impact of my message has been accepted. That message is that it is possible to look upon automatic routines for generating tutorial material for mathematics as a feasible alternative to the older forms of computer teaching machine compiler languages. While the notion of generation cannot be applied to all content material, mathematics is the area in which great progress can be expected. I believe that all current work on nongenerative or selective approaches to mathematics training is essentially wasted and should be replaced by a coordinated effort using generative techniques.

Reference

SKINNER, B. F. Ice cream for the right answers. *Forbes*, 1968, 102, 46.

Appendix 1

A SIMPLE EXAMPLE OF GENERATIVE COMPUTER TUTORING

WILLIAM R. UTTAL *and*
TIMOTHY W. PASICH

(1) *Frame Zero.*—The invisible (to the subject) format of the problem as specified by the teacher, showing the random variables and their ranges. All of this information must be typed into the computer. A very large number of similar problems are represented by this format expression. Any algebraic format desired may be specified with up to seven random variables.

(2) *Problem 1.*—General presentation. The problems in each case are randomly generated according to the algorithm described above and are not prestored.

(3) *Problem 2.*—The partitioning process automatically produced by the computer showing the descent to primitives along one side of the problem, ascent to the original problem and then descent along the other side. All steps are conditional upon the student's answer and are generated rather than prestored.

(4) *Problem 3.*—Descent to a primitive which can not be handled with our present program and the call for help which identifies the trouble. Later this call for help will be replaced with a drill routine.

(5) *Problem 4.*—Detection of a difficulty with a major operator. (Similar to 3) but a different programing algorithm is required.

—0— R1, 1, 3 R2, 1, 6 R3, 1, 4 R4, 1, 6 R5, 1, 6 $ A = [2] B + [3] X = (A + [4])*(B↑[1] – [5]) #	—1— Problem 1 A =1 B = 2 Using the values above, solve this equation for X. X = (A + 5)*(B↑2 – 1) X = 18
—2— O. K.	—3— PROBLEM SOLVED
—4— Problem 2 A = 3 B = 3 Using the values given above, solve this equation for X. X = (A + 4)*(B↑2 – 4) X = 30	—5— YOU GOOFED
—6— A = 3 B = 3 Try this expression A + 4 Exp = 7	—7— YSTYLC

—8—

A = 3
B = 3

Try this expression

B↑2 − 4
Exp = 4

—9—

WRONG

—10—

A = 3
B = 3

Try this expression

B↑2
Exp = 9

—11—

RIGHT

—12—

A = 3
B = 3

Good, try this one

B↑2 − 4
Exp = 5

—13—

RIGHT

—14—

A = 3
B = 3

Good, try this one

X = (A + 4)*(B↑2 − 4)
X = 35

—15—

YSTYLC

—16— PROBLEM SOLVED	—17— Problem 3 $A = 3$ $B = 4$ Using the values given above, solve this equation for X. $X = (A + 6)*(B\uparrow 2 - 1)$ $X = \underline{57}$
—18— INCORRECT	—19— $A = 3$ $B = 4$ Try this expression $A + 6$ $\text{Exp} = \underline{8}$
—20— WRONG	—21— $A = 3$ $B = 4$ Try this expression again $A + 6$ $\text{Exp} = \underline{7}$
—22— REALLY	—23— You are having trouble with addition. Please call your instructor.

—24—

Problem 4

A = 3
B = 1

Using the values given above, solve this equation for X.

X = (A + 1)*(B↑1 – 4)
X = –14

—25—

YOU GOOFED

—26—

A = 3
B = 1

Try this expression

A + 1
Exp = 4

—27—

CORRECT

—28—

A = 3
B = 1

Try this expression

B↑1 – 4
Exp = –3

—29—

RIGHT

—30—

A = 3
B = 1

Good, try this one

X = (A + 1)*(B↑1 – 4)
X = –11

—31—

INCORRECT

—32— A = 3 B = 1 Try this expression again A + 1 Exp = 4	—33— CORRECT
—34— A = 3 B = 1 Try this expression again B↑1 − 4 Exp = −3	—35— RIGHT
—36— A = 3 B = 1 Good, try this one X = (A + 1)*(B↑1 − 4) X = 12	—37— WRONG
—38— You are having trouble with multiplication. Call your instructor.	

Reaction Paper

J. S. McCONNELL
Senior Systems Designer, Philco-Ford Corporation, Willow Grove, Pennsylvania

(The remarks to follow were written in reaction to the original papers presented by Duncan Hansen and Karl Zinn on CAI Software Development.)

In contrast with Dr. Zinn, I am here as the representative of a vendor, and as one who has been associated with one major CAI Project—Project GROW—since its beginning. I embarked on that project as a specialist in computers rather than education. Or, as Dr. Suppes was quoted in *Life* magazine, one whose "ignorance of education is gargantuan." However, I do bring a certain amount of experience with me that may be useful to others—the experience of implementing a tutorial CAI system; of attempting to provide an author language that would satisfy the needs of curriculum authors and coders; and of attempting to build into the language and the system those data gathering and reporting features required by the teachers as well as by the researchers and authors.

Having delivered my apologia, I will now turn to the subject of this meeting. I will follow generally the outline of Dr. Zinn's paper, and will attempt to amplify, enlarge, or in some cases, contest his major points. However, the emphasis may be shifted to some other matters that I feel are important.

Modes of Instructional Use of Computers

First, I *do* use an acronym, CAI, simply because it is, and has been, the one most commonly used to refer to the instructional use of computers. However, I use it in its more restricted sense; i.e., the use of a computer to administer instruction. Under this umbrella I would include drill, testing, and tutorial instruction—in other words, those categories that Dr. Zinn has called author-controlled instruction. If this group wishes to vote on the acronym ACI instead of CAI (or CBI or CAL or . . .) I have no objection. But I do feel a need for a term that may be used by all to refer to this specific subset of the Computer/Instruction universe.

I agree now that we should not limit ourselves to this particular application of the computer in the instructional process. One danger in the use of an acronym such as CAI, with its rather loose usage, is that it does tend to contribute to communication gaps. Hence, because of the restrictive connotation in the past use of the term CAI, perhaps we need a new, more encompassing term. So much for semantics.

Dr. Zinn has stated that manufacturers tend to limit the scope of applications in order to market a system that is economical to operate. This is one part of the story. Another is the initial cost of the computer software. Dr. Hansen stated in his paper that the cost of a new CAI operating system is approximately 20 man years of labor. This is in the right neighborhood, but can vary 50 percent either way depending upon the features and the sophistication of the system. This represents an investment of roughly half a million dollars. For a vendor to spend this kind of money for programing alone, he must have some assurance that the effort is progressing in the right direction. This explains, in part, the inertia of vendors in adding new features to their systems. So it is up to the education community to carry out the experiments and to present their findings (and by extrapolation, their next-system requirements) to the equipment manufacturers, and to the operating system designers.

Three groups of instructional modes were listed for consideration in the present context:

1. Author Controlled Instruction
2. Simulation and Gaming
3. Learning Tools

As stated previously, author controlled instruction includes those modes in which the author controls the dialogue and guides the student through one, or a few, preordained paths. It could also, but generally has not, included problem solving by the student, under the guidance of the author. A notable exception is the PLANIT system, which includes a calculate mode, available to both student and lesson designer. Most CAI systems to date have included no on-line problem-solving mode, initially. Later on, a language such as BASIC or APL is sometimes added, but it is not usually linked directly into the CAI operating system. By this I mean that a lesson author cannot put a student directly into a calculate mode. Instead, the student must sign off of the CAI system per se, and sign back on with a request for calculation. While this is better than nothing, it is often a burden, and detracts from the educational process. Hence, one of the principal requirements of a system designed for instruction in mathematics is the inclusion of an easily usable computing language, and the linking of this mode with the author controlled instruction mode.

The preceding remarks have a direct bearing upon the second of the three modal groups, simulation and gaming. A system equipped with an author language designed for tutorial instruction, and which includes a directly-coupled calculate mode, probably has all of the features necessary for the implementation of a wide range of games and simulations.

I would like to add a few remarks to Dr. Zinn's discussion of the dimensions of computer usage in instruction. When speaking of CAI, I believe we have been tacitly assuming the context of the class room, with full year courses coded in tutorial or drill form. But I envision also a library-type of application, where instructional units are available on a terminal reservation basis. The units may be assigned by a teacher for outside work—in which case scores would be recorded and forwarded to the teacher—or the units might be suggested to the student, who could then run through the material as often as he desires. The form or mode of the presentation really does not matter. It could be drill, tutorial, a guided problem solving session, or a combination—whatever form is appropriate to the material and to the instructional objectives of the unit.

I might at this time speak of the terminal devices and of the economics of system operation. The type of terminal device used in a system tends to influence the type of curriculum developed, and also the number of terminals that will ultimately be connected. For example, teletypes are generally quite amenable to drill and practice, since there are relatively low volumes of data to print. There are also cases where hardcopy output is desirable, as, for example, in the problem solving modes. Tutorial instruction, on the other hand, involves a much greater volume of text. Students who can read adequately become quite impatient after the novelty has worn off. For this reason, Cathode Ray tubes are generally more preferable for this mode of instruction. I make these distinctions to support my contention that a properly equipped instructional system should include both types of terminals. Economics are a major consideration here, teletypes being less expensive than CRT devices, both in initial cost, and in the demands upon system resources needed to support them. A student can thus be assigned to the device appropriate to the material that he is to receive.

While considering the dimensions of modes of use, we should consider also the problems of integrating the CAI portion of a course with the traditional portion—if there is such. With drill and review material, as exemplified by the Stanford and RCA curricula, this problem is at a minimum. Each student receives a specific quantum of drill work each day, designed to reinforce what he has previously learned in class. The students in this environment progress as a group, and the teacher has few problems keeping track of individual progress. The generally uniform structure of the drills also eases the problem of paperwork for the teacher. It is very simple to make a quick check on the students, since they are always at the same point in a course, varying only by level of difficulty and score within the respective levels.

Tutorial instruction presents quite a different set of problems. This form of CAI was widely hailed at the outset. Great claims were made about its ability to break the lock step in education, to individualize instruction, to free the teacher for more personal attention, and above all to allow the student to proceed at his own pace. Each of these claims is true—theoretically. But the teacher may not be the recipient of quite as many advantages as originally anticipated. If we accept the concept of self-pacing as one of the attributes, we have the problem of class spread. A typical ratio of three-to-one has been observed in comparing the progress of the fastest to the slowest student in a fairly homogeneous class. It should be obvious in this case that the teacher would be hard pressed to prepare any sort of lecture after the course is under way. The answering of individual questions or the conduct of a lab is about all that the teacher could expect to do with the class. So we must consider the possibility that tutorial instruction should be parceled out in discrete quanta just as drill material is.

The student reports are another problem for the teacher. Some attempt is generally made initially to produce reports covering the totality of the student interactions (principally because the data is so easy to collect in a CAI system). This is usually a mistake, for two reasons. First, there is more data than the teacher can possibly analyze and digest. Secondly, the very nature of tutorial CAI makes the data more difficult to analyze on a comparative basis. The richness of the individualization and the possibilities for remediation afforded by the branching logic preclude comparisons among members of a class, except in the grossest sense. It appears that the best approach is to insert criterion tests regularly within the instructional material. These tests are devoid of the usual branches and retries, hence, the results can be summarized and reported in a form that is more meaningful to the classroom teacher. At the same time the lesson author is not constrained or required to maintain elaborate scores throughout the instructional sequences.

At the upper end of the dimensional scale, we begin to run up against the purely economic factors. The management of information under student control is an interesting concept. The ability to retrieve, rearrange and store large volumes of information is a useful tool for research and report preparation. Unfortunately, it requires a much more sophisticated operating system, a great deal of man power to enter the data into the system (until optical scanners come into more general use) and a large volume of secondary storage to contain the data. On a cost per student basis, it will be several years, I think, before anything of this nature can be justified.

Contributions of the Computer to Instruction

Speaking in terms of CAI; i.e., author controlled instruction—the principal benefit that I have observed in Project GROW is the dialogue possible between student and system. The benefits listed by Dr. Zinn—prompt evaluation of response and so on—are certainly factors in this. But the dialogue—the interaction—is the thing that keeps the students interested, and in fact oblivious of anything that is happening around them. If you have ever worked with children from disadvantaged neighborhoods, I am sure you know what it means to involve these kids.

Restraints Imposed by the Programing Language

Dr. Zinn has listed four classes of languages that have been developed for the instructional use of computers. As he says, the lines of division are not very clear, and many of the languages that he has surveyed can fall as easily into one classification as another. A large percentage can be categorized as problem-oriented languages, since they were designed to ease the problem of curriculum description in terms that a computer can digest.

Languages such as Philco-Ford's INFORM and IBM's COURSEWRITER fit almost equally well into categories two and four, since they are convenient for describing frames of instruction (in the programed instruction sense) and for specifying procedures involving more complex instructional strategies. What I am trying to point out is that the application of the language may define the category as much as the language itself. There are obvious limitations to most of the languages, and some obvious strengths in many of them.

One problem facing users is that of converting curricula from one CAI language to another. The cry is made for standardization of CAI languages. The point that is all too often overlooked is that most CAI languages are based upon a model or simulation of a teaching machine. Before we can standardize on a curriculum author language, it is first necessary to define the teaching machine upon which the language is based. There are several physical evidences of the model and many aspects that are invisible as far as most of those who interact with it are concerned.

For example, in Project GROW, the student sits at a SAVI terminal (Student Audio-Visual Interface). To him, the teaching machine is a window, through which he sees a certain amount of text and graphic information, and by means of which he is asked questions; it is also the light-pen, with which he can point to displayed answers, and the keyboard, which he can use to construct responses.

To the teacher, the teaching machine is all of these, plus the various reports of student progress which the machine provides. The teacher need not know or care about the techniques used to maintain the data and generate the reports. It is enough to know that there are counters running, whether real or simulated, that accurately record the essential aspects of a student's progress.

The curriculum author is much more aware of the internal workings of this simulated teaching machine. His principal view of the machine, in addition to the terminal itself, is the author language. The language completely describes the levers he can pull, the switches he can set and the bells he can ring. This is the heart of the machine, where we can find the score keeping and lesson controlling apparatus. It is this simulated apparatus that distinguishes a true CAI language—and operating system—from those languages that have been used for instruction, but were originally intended for other tasks. It is this apparatus that assures some uniformity from one course to the next. Without it, the author must, in effect, design his own model. This may be acceptable for the individual researcher, but it simply increases the problem of comparing the results of different CAI projects, and increases the cost of curriculum preparation wherever complete performance data is to be maintained.

I would like to close with the claim that standardization of the teaching machine model is the prerequisite to standardization of the language. This includes both the physical features—character set available on the keyboard, capabilities and characteristics of the display, etc.—as well as the simulated features, such as number and size of counters, the primitive operations that can be performed, the data to be maintained automatically by the system versus that to be maintained by the author, what can be saved by the system from session to session, and so on. These are the essential features—the language is only a manifestation of them.

PART III

THE DEVELOPING ROLE OF CAI IN EDUCATION

ROLES AND DIRECTIONS IN CAI

GLENN C. BACON
Systems Manager, Education Systems, IBM Corporation, San Jose, California

The purpose of this paper is to explore the factors which will be involved in the development of CAI. I think a useful context in which to do this is to elaborate upon the roles which the key elements of the CAI community might be expected to play. For purposes of this discussion, I would categorize these elements as publishers, manufacturers, and educators. After discussing these roles, I will focus on the way I see these groups interacting and speculate on the directions which CAI might be expected to take.

The Publisher

Probably the least discussed, but the most critical, is the role of the publisher. The importance of the publisher's activity derives from the central nature of the instructional materials. To him, the computer is a new medium—a medium with dimensions beyond those available to traditional materials of instruction. In CAI there is an opportunity for his author and editor to explore a multitude of new approaches to the teaching task in search of improved learning.

Along with this additional capability comes an increased degree of complexity. The skills required to produce good CAI materials do not necessarily reside within the publisher's current editorial and publication staff. He might take on aspects of the complexion of a programing software house. Beyond the obvious requirement for programing skills, this will require that he establish a maintenance function. It may not be obvious, but modern computer software requires considerable maintenance and an extensive documentation scheme in order to manage the maintenance problem. Addi-

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tionally, the requirements of good programing design imply that he impose appropriate disciplines to insure the interchange of course material.

It is not my intention to paint an overly complex picture of the publisher's role. Rather, it is to point out that the flexibility and dynamic aspects of this new medium bring with them additional management and logistic considerations that are not now within the traditional role of the publisher. Even with these additions to the publisher's role, his major responsibility of providing appropriate educational materials remains paramount. In fact, the speculation that hardware manufacturers will significantly influence what is taught in the classroom seems to be to be ill-founded. The publisher, with the author, will continue his traditional role of providing the school with a portfolio of educationally sound offerings and the determination of educational value will reside primarily with the educator and the publisher.

The Manufacturer

The major responsibility of the systems manufacturer might be characterized as providing an appropriate systems environment for the publisher's and educator's handiwork. He will have a considerable interest in understanding those areas where significant educational value can accrue from CAI approaches. This interest is expected to yield his better design in order to further facilitate such approaches. The challenge for the manufacturer at this stage of CAI development is to determine those significant trends which will have broad utilization.

In order to insure that the benefits of modern technology can be realized, it is crucial for the educator to understand that the high development costs and the expense associated with tooling and process manufacture require that a significant volume of production be achieved. Accordingly, the full promise of CAI, as it requires equipment which is specialized to its own use, will not be realized until this focus is found.

The Educator

The role of the educator, however, has a unique element for he has the responsibility to articulate the overall educational goal which CAI is attempting to serve. As a consequence of his responsibility for overall goals, the educator has two major decisions to make. First, I would speculate that the most important consideration he faces is deciding if the current way in which he manages his school and his classroom is adequate to meet his goals. It is possible that the changes which will ultimately evolve in the way schools run themselves will have a far more significant implication for American education than the effect of CAI in that situation. Secondly, once he has decided how better to manage the teaching-learning process, he must then articulate the technology requirements which derive from this environment.

I would like to expand on these two dimensions of change in education. The focus on overall goals will yield a change in emphasis from one of method to one of specification of objectives. These objectives will cause a degree of measurement on the learning process which does not generally exist. Such measurement in itself will greatly increase the rate of innovation in education, for through measurement the additional work that is required becomes clear. Additionally, goals set for the learning process should cause an expansion of its involvement in the other aspects of society. Specifically, the role of education in the home and throughout a career will become firmer.

With the overall educational environment thus specified, the role of CAI can come to a much sharper focus. A proper characterization of this environment will define the degree of individualized instruction required. It should further define the information retrieval, simulation, and administrative support which a school must have to meet its goals. This characterization of environment should also specify what costs it is willing to pay for various instructional capabilities. In this manner, an appropriate differentiation among CAI, instructional television, programed text, and the multitude of other approaches can be achieved. The value which each of these approaches brings, and consequently its ultimate place in the educational community, must derive from the overall direction of the educator.

In other words, it will be the value system of the educational community that will determine the worth of the various instructional technologies. It is through articulation of this value system that the educator will effect his leadership.

Directions

Having briefly outlined the tasks of the principals involved in the progress of computer-assisted instruction, I would next like to explore the directions in which this field might progress.

Each of the parties which I discussed is the holder of unique resources: the publisher and manufacturer with their development and distribution skills, and the educator with his knowledge of the teaching-learning process and the practicalities of school administration. Progress is critically dependent upon each of these elements being brought to bear in a mutually supportive way on the problem.

The key to progress, in my opinion, is the maintenance of an attitude of evaluation. CAI is still in a development phase in terms of both its educational value and its appropriate place in schools. Each of us associated with the field is probably able to point to specific accomplishment and promise for the various projects within his cognizance. However, I think each of us must frankly admit that there are more problems to be solved than have been solved. And further, consistent with the development of any new area, we should expect that many of the approaches which are now being tried will not be successful. This is characteristic of any research and development effort and I think should be expected in our situation. With this in mind then, and the expectation that CAI has ultimate promise, the intelligent management of our respective aspects of this national resource demands that we each keep the utmost objectivity toward the various projects in our domain. It demands that we state very clear objectives for what we are trying to do with CAI and be constantly measuring and evaluating our work against these.

In this attitude of evaluation, let me first address system design. From this viewpoint it is important to assess the relative maturity of the technological aspects of the system. Specifically, the continuous improvement in semiconductor and magnetic technology has allowed a rapid decrease in the cost per computation as it is associated with the CPU and main memory. On the other hand, the cost of terminal hardware, especially that which has a high mechanical content, has not shown nearly the same rate of improvement. In that regard, current trends of CAI are perhaps unbalanced. I am not repeating the oft heard accusation that most current work is mechanized page turning. It is clear, however, that the greater portion of system cost is spent in managing the mode of presentation as contrasted to implementing the instructional strategy itself. In terms of the learning benefit, this seems to be an improper allocation of resources, and as I see system trends, the unbalance could become even more marked in the future.

Pursuing this point further, CAI seems always to be addressed in the context of a conversational system. While many unique capabilities accrue from this approach, there are many important instructional applications which may be served with an off-line, batch approach. The obvious example is the use of the machine in the computational aspects of problem solving. Here assistance is given to instruction through allowing the student to take design and analysis problems to conclusion when without the computer, only formulation and partial solution would be practical. Beyond this, it is practical to do simulation in the batch mode. And, of course, the various approaches to instruction management are done on an off-line basis.

Along this same line, I would like to agree with the earlier comments of Dean Gerard, that more heuristic and deductive inquiry based approaches will follow in the future. These will certainly increase the central processor usage and decrease the percentage of time that the system spends simply managing the input/output equipment. Further, I believe that inquiry systems will be of significant importance in the teaching of higher mathematics and would like to further pursue the comments of Professors Greenberg and Andree in this regard.

The computer, it would seem, has unique capabilities for allowing the student to manipulate larger concepts and to help him visualize these in a way that might not be practical with any other medium. Let us hypothesize a graphic system which is learner-directed. The system provides a mathematical environment within which the student can inquire and test hypotheses which he may have about particular mathematical structures. In this way, he can test and generalize his understanding and consequently develop a "feel" for the particular area of mathematics.

Particularly, it might be possible to display the multiplication table of a group and show within that the elements of various subgroups. The system might allow the student to see various properties of the group change as he redefines the way in which it is generated. Further, the area of differential equations could be well served by such a system through allowing the exploration of properties of solutions. The student could change boundary conditions and integration constants and see the effect. Concepts of stability could be better understood. I have seen such a system also used in electrical engineering to study the solution of transmission line problems.

Further, one can think of examples that visualize such concepts in analysis, spectral theory, set theory, and statistics. The main reason, again, that CAI is valuable in such a context is that it provides the dynamic environment within which the student can hypothesize and test his conjectures and develop generalizations upon which mathematics is built.

Next, consider the effect of CAI on its environment. Many social critics have worried over the possible conformity which may result from giving the computer a role in the classroom. Somehow, it is conjectured, students will all be shaped into fixed formats like holes in a card. I would like to contend that this is a straw man. Certainly society can use the computer (and a great number of other tools) to foster conformity. On the other hand, its logical and memory capabilities can allow a diversity which was not previously possible.

Not only is it hoped that CAI will facilitate each student's taking his own appropriate route through a particular subject, but it is also expected that an instructor can vary a great number of parameters which define a particular piece of computer-based instructional material. In such a manner, he might control level of difficulty, proficiency, frequency of testing, etc.

An additional element of diversity is attendant to the logistical flexibility which CAI allows. System and terminal availability are the only significant constraints in the conversational mode. In an off-line mode, the movement of paper is the only practical concern. Consequently, as CAI approaches mature, the educator should expect considerably more latitude in the way the instructional task can be managed and should be sure his goals take this into account.

Many have stated before, and I certainly concur with the point that the pacing element in the development of CAI will be the availability of good materials of instruction. As was discussed, this availability depends upon the ability of the publishers to augment their staffs and facilities to produce these materials. However, there is a very key step which precedes this. That step is one of active experimentation which must produce answers to questions about the appropriateness of CAI as a function of grade level, subject matter, instructional strategy, media usage, systems design, etc. As I alluded earlier, there are more unanswered questions in this area than there are conclusions. Before significant investments will be made on the part of the publishers, I would conjecture these answers must be more evident. Certainly a number of publishers are now investing in CAI and some very interesting materials are available. However, before the broad investment is made which will be required for the portfolio of materials that the educator will need, the results of much of the current educational research and development must be made available and assessed.

There is an additional issue which may or may not be classified as CAI, but it is nonetheless computer related, that I would like to bring to the attention of this conference. More and more, vocations are being served by the computer. The industrial professional has computer programs in which he entrusts a significant amount of design prerogative. These programs are, in effect, his major tools.

I would like to suggest that as a student goes through school, he too, should be expected to accumulate such tools. And upon graduation, he would have a portfolio of computer programs which would generally augment his strength in design, analysis, or any other analytical task for which he was trained. I believe that the preparation of any technically related curriculum should include, as an objective, the design of programs which the student takes away with him as lasting capability. I think there is particular import in this concept for applied mathematics.

Finally, let me conclude that the evolution of CAI usage will be iterative. That is, each of us, the educator, the publisher, and the systems manufacturer must take approaches with the hope that each successive step is converging toward a more useful educational result. I thus return to the point—the maintenance of an attitude of evaluation is absolutely essential at this point of development. Otherwise, the possibilities of convergence seem much more remote. We all must be prepared to put an extraordinary effort in measurement and study and we must be prepared to discuss with each other the view which he has of our role and our interaction with him. In this context, we must look to the educator to be the keeper of the overall goal and direction in which the educational environment must take. This leadership carries with it an attendant obligation, however, for these directions must be stated in terms that are meaningful to the other participants in this iterative evolution. He must maintain the broadest possible approach to the task. I would characterize this as a systems viewpoint. There has been much criticism of the systems approach in education. Specters of mathematical analysis and overquantization of imprecise and unmeasurable situations are always raised and systems analysis is deemed an antihuman activity. Again, I would contend that this is a straw man, for the systems approach is really an approach of looking at the whole of the process which is under consideration in the context of its overall objective. The essence of the analysis problem is to determine the role and the interaction which each of the input components plays as it pertains to this objective. In this context, the systems approach is merely a guide to thorough and logical thought.

I would like to close my remarks with the admonition that we must all ask questions of each other and attempt to guide our work in the context of such an approach. For only in this manner will we have any assurance that the actions which each of us intends to take will assure further convergence towards the educational goals which we are trying to serve.

THE COMPUTER IN EDUCATION

CARROLL V. NEWSOM
Vice President, Education, Radio
Corporation of America, New York City

This conference is concerned with the use of the computer in instruction, especially those aspects of the subject frequently categorized under the heading "Computer-Assisted Instruction" or "CAI." When considering such specialized methods of instruction —methods which have already shown great promise when properly employed in the proper circumstances—it is very easy to become so engrossed with the specific subject under discussion that the relationship of that subject to the larger universe in which it is a part may receive too little attention. So, at the very start, I feel obligated to attempt to create an appropriate perspective upon our considerations.

Education, as we all know, pertains to the very nature of life itself. In the phraseology of the modern psychologist, the processes and activities which we describe by the word "education" are for the purpose of bringing about changes in behavior. And we now know that men are so different in their abilities, in their interests, and in the manner in which they are motivated that there is no universal prescription for educators to apply. George Washington is reputed to have said that "The minds of men are as different as their faces." It is my present judgment that Washington's statement might well be rephrased to read, "The differences in the minds of men are very much greater than the differences which one observes in their faces." Present-day emphasis upon individual differences is more than fad; we are beginning to penetrate to the heart of the complex of problems that have beset education in the past. We must recognize the fact that each child coming into our schools is a product of his heredity and, of the greatest importance, he is a product of the environment in which he has spent the previous part of his life.

To further complicate the task of educators, Jerome S. Bruner, in a recent article (1968) wrote, "The process of education goes forward today without any clearly defined or widely accepted theory of instruction. We have had to make do and are still making do on clever maxims and moralistic resolutions about what instruction is and should be." The fact which Bruner enunciates is well known, but it is good to have it stated in such an explicit manner. It is of the greatest importance to realize that no developer of instructional resources and devices has a theory of instruction upon which he can build.

Thus, I see no alternative to the proposition that persons and agencies serving the broad needs of education have the responsibility of conceiving and developing a variety of instructional materials and devices; the purpose would be that of making it possible for an individual teacher or a group of teachers to select the items that will best provide the desired components and the necessary support for a specific instructional approach that is being advocated for a specific student when he is trying to understand a particular concept or learn a particular skill. It must be assumed, in other words, that a diversified array of instructional methods will be current among members of the teaching profession. A particular instructional resource or device possesses significance only insofar as it can become a useful element of an instructional environment, created and controlled by men, that hopefully will provide a climate in which a student can and will learn that which he is expected to learn.

The recent report (1968) of the Research and Policy Committee of the Committee for Economic Development, entitled *Innovations in Education: New Directions for the American Schools*, emphasizes that "The new educational technology . . . holds considerable promise for improving the quality of instruction. No opportunities to advance education through new technology should be overlooked. However, our interest in instructional technology increases rather than lessens our concern for improving teacher education and developing better curriculum materials. For however sophisticated and useful the machine may become, it will always be an instrument employed by human educators. We see no conflict between teachers and machines, but rather the opportunity for teachers to become more effective through the use of machines. The substance and quality of education must always depend on the knowledge, wisdom, and ingenuity of scholars, the designers of curricula, and, most important, teachers who work directly with children and teenage students."

It is not new to provide various kinds of resources to teachers to assist them in creating the kind of instructional environment which they may desire. Teachers have used chalk; they have used blackboards; they have used maps; they have used textbooks; now, chiefly because of the great advances in technology, many other supporting materials and devices have become possible. One does not ask whether a piece of chalk can teach; such a question is inappropriate. Similarly, one should not ask, "Can television teach?" Television is designed to transmit from a distant location a visual and audio record of an event; insofar as such a record transmitted by television has significance for a particular instructional program that has been created for a particular student or collection of students, television has value. If a piece of chalk is improperly used in the instructional process, or if television is improperly used, fault must be found with the individual who creates and controls the instructional environment, not with the instruments that are employed. Recently I have read articles that attempt to answer the question, "Can computers teach?" Again, such a question is inappropriate. The computer possesses tremendous versatility and, when rightly used, can provide valuable ingredients in many kinds of instructional environments; when the use of the computer in the instructional process is improperly conceived, the individual who developed the concept is at fault.

Now the good teacher, as he attempts to carry out his responsibilities, can employ a multi-media approach. When developing an exposition of a concept, the medium or a combination of media can be chosen that would seem to be most effective—when weighed against the needs of the subject matter as well as the mental characteristics of the student. The study of various kinds of printed materials will always remain a fundamental part of most kinds of instruction. However, now it is possible, through the use of recordings, to hear a poet read his own works. Now it is possible to observe films of wave action in water to supplement and illustrate mathematical demonstrations. Now it is possible to simulate, by use of the computer, the behavior of an airfoil in a stream of air without the necessity of placing the airfoil in a wind tunnel; the observed behavior can be checked against theoretical determinations. Computer simulation is becoming increasingly important. Now it is possible to add a camera and projector to a microscope so that an entire group of students can observe the behavior of bacteria in a drop of water from a pond. Now, by means of television, students can be in the audience when the President of the United States is inaugurated. Films of solar flares can be made when the flares occur and stored for future display before students. Computerized systems can be employed to guide a student to have many kinds of significant learning experiences. Such a list can be extended in an unlimited way. Certainly the imaginative teacher now has the opportunity to create an instructional environment to serve the specific needs of his students that will be fantastically rich in the learning opportunities that are provided.

Computer-assisted instruction—and I warn you not to interpret the phrase in too narrow a fashion—will certainly play a variety of roles in the complex of instructional endeavors that will be common in the future. Hopefully, each variety of a CAI program can make a significant contribution as a component in each one of a multitude of instructional endeavors, but it must be assumed that wise judgment will determine its proper utilization and whether it has a proper use in a particular instructional activity. A creator of a CAI program, therefore, has an obligation, let me emphasize, to assist curriculum designers to understand the objectives of the program, how it is to be employed, and the outcomes to be anticipated as a result of its use.

To carry out the program of education for the schools, and to some extent, the colleges of the future, as I have envisaged its development, requires greater sophistication in our guidance programs. A glimpse of the future use of the computer in this connection is revealed in a recent article by William Turnbull (1968), Vice President of Education Testing Service. He wrote: "It seems to me that we should work toward a system for collecting, on a regular basis, information about each child's performance as he passes through the school system—a record of his accomplishments in terms of grades and standardized tests, his interests, his extracurricular activities, and so on. We need to find a way of organizing this information efficiently, of expressing it in an unambiguous language that can be communicated to other people and manipulated rationally, of storing this information and of retrieving it rapidly for use in pupil guidance within and between educational levels, including grades 12 and 13." The very important computer usage, which Dr. Turnbull anticipates in his article, must be regarded as within the definition of CAI.

During this conference many illustrations of computer-assisted instruction are being discussed and analyzed. A vast number of students in our schools and colleges, along with research personnel in industry, are using the computer to solve long and complex arithmetical problems and to simulate the data structure of experimental situations that previously were handled almost entirely through the creation of laboratory experiments or a study of actual cases. In addition, computer-controlled "drill and practice" exercises are being employed in a variety of academic institutions to supplement and extend the regular instructional program in certain subjects, and success has attended several efforts to program a computer to carry on a Socratic dialogue with a student who is attempting to become proficient in a particular area of knowledge. Computerized language teaching has been remarkably successful. The computer is being employed in medicine to provide the student learning experiences in the area of diagnosis. There is virtually no limit to the possibilities of programing a computer to interact with a learner in such a way that effective learning experiences are provided. It is inevitable that the frequent achievement and diagnostic tests that will become an intimate part of many curricula of the future will be under computer control.

I find an element of excitement in the fact that computerized systems of instruction for providing learning experiences in the home, admittedly of a primitive type, are now being demonstrated. It is inevitable that the computer will become an adjunct of present efforts to provide television instruction in the home, in individualized student study cubicles, in industrial learning centers, and elsewhere. The concept of CATV will certainly undergo modifications to provide for the origination of recreational and educational services along with the rebroadcasting of network programs; it will be in this connection, in my belief, that the computer may well become the vehicle for relating instructional activities in the home to the instructional endeavors of the schools.

Although it is anticipated that teachers will provide an active, personal element in most instructional environments, there is no implication in such a point of view that teachers must always be physically present. It is inevitable that technology will be employed to make possible the creation of specific kinds of instructional environments where no teacher will actually be present. In fact, this is desirable when fostering programs of independent study and many kinds of group study. Nevertheless, even in such a case, the design of the instructional aspect of the environment, including the program, must be the responsibility of knowledgeable educators.

In line with comments already made, I must think of CAI as encompassing many kinds of computerized instructional activity. It is my belief that the computer will inevitably become the dominant component of the physical systems which provide the structural framework of the instructional environments of the future. The versatility of the computer defies imagination. Few persons appear to understand that our remarkable accomplishments in space exploration have been possible only because of the availability of the computer. The good manager in industry is finding a multitude of ways in which the computer makes possible greater efficiency and economy, and now he is inaugurating and using analyses and procedures that were regarded as impossible only a short time ago. Too many educators, however, have been slow—yet, I believe, understandably so—in recognizing that the computer can be their servant in carrying out with amazing speed and correctness many of their traditional tasks such as record keeping and the issuance of grades and transcripts and also can make possible a great variety of highly desirable professional instructional and related activities that were in the realm of the hypothetical just a decade ago.

Librarians and the scholars who must use the libraries have become excited by the fact that computer capabilities make possible more useful schemes of cataloguing library items, the ready availability of many correlations between concepts, possibly from diverse fields of knowledge, and a rapid retrieval of needed resource materials. The computer, in combination with the other new-type mechanisms and communication devices, will also facilitate within a comparatively short time a quick and easy access by teachers and students to desired audio-visual information stored in central resource centers; this one development can well bring about a revolution in the techniques employed by the teacher and it will greatly facilitate the creation of a variety of ways to provide opportunities for independent study.

By combining with computer capabilities some of the basic principles behind the visual displays of television, it has become possible, when creating printed materials, to move directly from editorial offices to the printing plant. In other words, a new-type editor can instruct a computer in regard to the printed material which is to appear on a particular page as well as the format into which the material is to be cast, including any illustrations that may be desired, and the computer, in "a flash of an eye," will provide him an electronic image of the page, pursuant to his instructions. The editor can peruse the image and possibly instruct the computer to make a variety of adjustments on the image of the page to suit his fancy. The final, approved image, usually translated under computer instructions to a metal plate, is then ready for the printer. And, interestingly enough, the editor may be seated before the console of a computerized graphic system here at Penn State University, and, by employing the long distance telephone lines, the finished pages as he has designed them with computer help may simultaneously roll out of a mechanism in Chicago, in Dallas, or in San Francisco. Each morning, daily readers for students and other kinds of printed information, very much up to date, can come out of machines in all the schools and colleges of the nation. Fantastic? It is possible at the present time.

The computer, no informed person now doubts, is destined to bring about fundamental changes in the instructional techniques and programs of our schools and colleges. It is likely, however, that many of the changes which in future years may have tremendous significance have not yet been conceived and, in fact, their conception is probably beyond existing capability. Presently it is only possible for educators to have a glimpse of what is ahead. It is also important to note that the computer and related technologies will also, ultimately, have an effect upon instructional philosophies and will stimulate new-type research endeavors pertaining to instruction and learning.

In spite of my optimism, as I look into the future, in regard to the values of the computer for the field of education, we must, if we are honest, admit that computer systems designed to meet education's needs are still in an early stage of development. Although I am very conscious of the shortage of well-conceived instructional programs adapted to the computer, usually described as software, I am becoming increasingly impressed with the necessity for relating in an intimate way developmental efforts in hardware with those in software. In addition, economic restraints are becoming recognized as a dominant factor in virtually all efforts pertaining to design, of both hardware and software. Much developmental effort is required before computer systems will be available that will satisfy the variety of school and college requirements for both administrative and instructional purposes as enunciated by knowledgeable educators. It is especially true that the development of essential peripheral equipment has produced new and difficult challenges to our engineers. But, in view of the present-day interest of many industries, of publishers, and of others in the utilization of the new technology for the benefit of education, intensive, and I may say "expensive," efforts are under way in an attempt to solve the developmental and design problems which have become apparent. Moreover, it would be tragic if there is too much delay on the part of teachers in the use of CAI as a component of their instructional endeavors; CAI, even its preliminary forms, has considerable educational significance, and essential progress in our understanding of computer utilization for educational purposes demands analysis of actual experiences of teachers and students.

In the past, when speaking of instructional materials, the implied reference was to printed materials. The copyright laws were designed to protect authors whose original ideas were cast into print. Now, with the new technological developments, the situation has become badly scrambled, and major controversies are occurring in regard to appropriate revisions of the copyright laws. My own involvement in current discussions has made me very uncertain and cautious in regard to virtually any program of revisions that has been advocated; some of the problems that are involved are taxing the ingenuity of our best legal minds to develop equitable resolutions. It is my judgment that authors of new-type instructional materials for computer systems that display acceptable originality will receive protection in any ultimate revision of the copyright laws. The greatest difficulties encountered in developing desirable revisions of the laws relate to the ease with which published materials, including copyrighted materials, can be duplicated by employing recently developed technological devices; this duplication may be carried out in a variety of ways, including, as a possibility, duplication in the memory unit of a computer.

The rapid growth in the use of the computer as well as other technological devices in the instructional process has served to trigger significant analyses of traditional programs of the schools and, to some extent, the colleges. Such analyses have been further stimulated and reinforced by a growing belief by both educators and non-educators that, in spite of the vast amounts of money this nation has spent on education, the schools have been singularly inefficient and ineffective. As a result, a substantial part of the educational world is in ferment. There is a strong desire on the part of educational leadership to do a better job. And enlightened educators see in the proper use of modern technology the kind of assistance that teachers need to do that better job; they see new opportunities to carry out the precepts advocated by experts upon the learning process.

Although curriculum designers can make a contribution to the educational progress that is being sought, although individuals and organizations can develop and produce hardware and software ingredients of possible instructional environments, the ultimate design of an instructional program to serve the proper purposes of a student or collection of students belongs to a teacher or teachers. The teacher of the future, therefore, must be a very special person;

he must be a counselor and a manager as well as an individual who possesses both a broad and a specialized educational background. Moreover, we must develop techniques to enable the good teacher to carry out his responsibilities in an efficient manner.

So I believe that it was most appropriate that the special committee of the Committee for Economic Development (1968), to which reference has already been made, should incorporate the following paragraph in its report:

> Schools of education should examine their curricula to ensure that their pedagogical studies are effectively tied to educational purposes and goals, subject matter studies, and the improvement of school curricula and instructional technology. The preparation of teachers should be geared to the major developments in educational research and to the improved staffing patterns of the schools. The schools need variety in the talent and function of their teachers rather than sameness and standardization. They need teachers who are capable of grasping the value of new ideas and are able to move in new directions when the evidence warrants. We urge the institutions engaged in the preparation of teachers to design their curricula to include adequate instruction in the values of research and the uses of advanced educational media. Institute programs to upgrade and update teacher competence have already proved their value. These programs, made available at leading universities to practicing elementary and secondary teachers, should be designed to improve both subject matter competence and capability in utilizing advanced teaching technology.

It is of significance to note that the computer has already become the symbol for the strong innovative trend that now exists in education. Unfortunately, the necessary experimental and developmental aspects of many of the innovative efforts now being advocated are expensive—often too expensive for the schools and even too expensive for the industries that are trying to serve the needs of education. There appears to be no substitute for a continuation of strong governmental support. I have no doubt that the cry for better educational opportunity, especially on the part of the underprivileged of this nation, will provide motivation for more and more educational innovation along with the financial support from government that such innovative endeavors require.

As a parenthetical comment at this point, I am beginning to believe that motivation for more experimentation in the use of educational technology will come from the attitudes of students. In my observation of students who are participants in computer-assisted instruction, I have been fascinated by the extent to which they personalize their mechanical teacher. For instance, recently I asked a youngster seated before a CAI terminal how he likes his new teacher. After some hesitation he replied, "I like it; I like it very much." "But," I inquired, "Why do you like it?" Again, after much thought, the student replied, "I like this kind of teacher because he likes me." Another young student, when asked the same question, said, "I like this kind of teacher because he doesn't know that I am black." Often a student will greet his computer terminal when he sits down before it and then will bid it "good-bye" when the lesson is over. It would be good indeed if some of the critics who fear an "impersonalization of instruction" brought about by greater use of technology could observe such reactions.

I cannot resist the temptation to conclude this paper with a statement directed essentially to teachers of mathematics. The basic thesis of this paper is closely associated with the fact that we are moving rapidly into an era—more rapidly than many persons appear to understand—when most professional people and those engaged in scholarly undertakings must have some comprehension of the digital computer, its operation and its programing. The computer is becoming an invaluable tool in a remarkable variety of endeavors; it simplifies many activities and makes possible some undertakings that were regarded as beyond the scope of man's capability just a few years ago.

Because of its significance for such a large segment of the population, especially for our future citizens, computer science must become a part of the curriculum of both secondary school and college. As would be true in the case of any subject introduced into the academic program, determinations must be made by competent educators in regard to proper methods of exposition, and attention must be given to the appropriateness of course content for any particular student or collection of students. Veteran curriculum experts know that it is essential, if a new and important area of knowledge is to be presented to students in a proper manner, that it must be included as a subject for exposition in one of the traditional disciplines that are components of the present, rigid discipline-oriented curriculum. It is my judgment that such an analysis leads to only one reasonable conclusion: elementary computer programing and the elementary principles of computer science must be accepted by instructors of mathematics, especially in the secondary schools and in the Freshman year of college, as a proper subject for them to treat in their courses. It is not difficult to find a basis for classifying computer science within the framework of mathematics; even more important, computer science provides a vehicle for developing explicit formulation of problems for solving many kinds of problems, and for illuminating many mathematical principles. The New Math, from my perspective, can no longer be regarded as new or even modern if computer science is slighted.

I have never been able to explain the fact that teachers of mathematics have not considered an exposition of the slide rule to be a natural extension of their treatment of logarithmic scales. If the teaching of computer science is similarly ignored, the consequences could be tragic—for our students and for the prestige of professional teachers of mathematics. Those who are members of the profession of mathematics, both teachers and creative scholars, have a special opportunity and a special obligation to be in the forefront of creative and developmental activity that pertains to computer utilization.

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CONFERENCE SUMMARY

HAROLD E. MITZEL
Assistant Dean for Research, College of Education, The Pennsylvania State University

When Dr. Heimer first spoke to me about this conference summary job I was very eager to do it because I thought there would be no advance preparation. But as today got closer and closer I began to fear the consequences. So you'll understand if this summary seems incoherent. It wasn't the fault of the people who made presentations. It's just that I didn't get my preparation done rapidly enough. I've been updating, as you might guess, all morning.

Dr. Gerard made a point, I thought, at least he became "one up" with the story about the mental patient. Those of you who were here the other night will recall his very interesting story, which emboldened me to tell one about mental patients.

It seems that a hapless motorist was driving along the road near a mental institution and had a blowout. As he pulled over to the side and stepped out to survey the damage he began to acquire a small crowd of inmates behind the fence, quietly watching and wondering what he was going to do about his predicament. Well, he thought he couldn't get any help from those folks so he set about to change his tire, that is, to remove the flat and to put on the spare. So he got out the jack, pumped up the car, and took the wheel off. He very carefully put the lug nuts in the hubcap and laid it out in the road behind him. Well, he had no more than gone to get the spare than a truck came along and knocked the hubcap with the nuts into the weeds. He searched for fifteen or twenty minutes and he couldn't find any of the lost nuts. So then he started swearing and wondered what he was going to do, finally deciding that he would have to hike off down the road to the nearest service station.

The watching inmates set up some derisive laughter and kidded him along. He said, "Well, you're so smart, how would you fix this?" One of the inmates said, "Well, really it's very simple. You have three wheels on the car yet, each of them has four nuts on the wheel. What you do is remove one of the nuts from each of the other wheels and use those lug nuts to put your spare tire on where you had the blowout." The man turned to him and said, "You know, that's a good idea, I think I'll do that." So after he finished and just as he was about to drive off the motorist said, "Say, how come you're in here? That was a very creative, inventive solution that you offered for my problem." And the spokesman for the inmates said, "Well, we're in here because we're crazy, not because we're stupid." I sometimes wonder if we are in CAI because we're crazy or because we're stupid.

I have prepared a kind of chronological reaction to the highlights of this conference, as seen through Mitzel's "Handy Dandy" filter. You have been introduced to a lot of wisdom in the last two days and I regret that I cannot respond adequately to all of it. So I have been very, very selective in picking those things that interested me and I hope you'll bear with me if I omit your favorite highlight.

Dr. Gerard referred to a dialogue regarding the definition of the business that we're in. That is, whether it is CAI—computer-assisted instruction, CAL—computer-assisted learning, or CBI—computer-based instruction. It occurred to me that this is really not inconsequential, but rather goes to the heart of the understanding of the application of this new technology. In other words, what you call something is more than just semantics. What is trivial and of no consequence is that some people have tried to associate each of these generic terms with a different hardware manufacturer and I don't believe that we have time for that kind of nonsense. I guess that computer-assisted learning has a kind of sound that bothers the psychologists, myself included, because of the ephemeral nature of some of the alleged differences between pre and post test results. We've all become aware of instances where the *process* of instruction took place, yet no apparent change in behavioral potential occurred. I think that it's on this point that it bothers the psychologist to talk about it as computer-assisted learning. Learning is the hoped-for result of a process or procedure, but is not the procedure itself. I happened to be present when Dr. Gerard and Professor Suppes went through this exercise with Pat arguing that it was computer-assisted instruction and Dr. Gerard holding stoutly, bless him, for computer-assisted learning.

I think Dr. Gerard coined a phrase and spoke wisely when he said there has been a revolution of expectations for CAI just during the last five years. I think we may confidently expect another revolution in the next five years, along this same line. Drawing on his extensive background in physiological research, Gerard pointed out how a quantum increase, in the richness of the learning environment which may conceivably be an outcome of CAI, can markedly contribute to the long-term improvement of *Homo sapiens*. This was a new idea for me and it does lend a kind of enobling quality to our mutual efforts to improve man's learning.

Yesterday, Dr. Bitzer took 27×10^2 seconds (that turns out to be 45 minutes, incidentally) to give us a fascinating glimpse of the future of hardware configurations for computer-assisted instruction. His presentation taxed my credulity when he got to 4,000 student stations, all connected to the same central processing unit. What are the implications of this vision? Well, it seems to me that it restricts CAI development to large institutions which have some 20,000 to 50,000 learners, or we are going to have to develop some community action program (where the community is defined as the educational community), or some consortia, or something, in order to be able to use adequately such a monstrous hardware configuration. And, I think it has some definite implications for the implementation of CAI. By restricting CAI to large monolithic administrative and electronic configurations we will too early squelch the creative and developmental inputs of a great many educators and computer specialists. I guess I had hoped, and still do, for a somewhat leisurely development along decentralized lines in order to get creative input from many different people and organizations. You see, if you make a mistake in and with a 4,000-terminal terminal system, that is a "lulu." In his summary, Bitzer reaffirmed his view that software, that is CAI education programs, and an inadequate knowledge of the learning process were the central problems of CAI. Many different CAI groups will be more likely to overcome this handicap than will one or two large organizations. There has been an overemphasis of the state-of-the-art analyses by saying, "Well, the trouble with CAI is the software." You and I know there isn't any software to speak of. The thing of it is that there is a very special developmental sequence here and that the hardware has got to come first. That is, you've got to have something around with which to develop the content material and you have to have some kind of hardware that is going to be viable long enough in order to make your curriculum efforts have a half-life of at least two years. So it is just too easy a generalization to say, "Well, the trouble with CAI is we don't have good enough software."

The real trouble is that hardware and software are inextricably linked together and you have to find ways of getting hardware in order to conduct the software effort and make it so that it will last. At Penn State we have not had any luck in trying to develop software in a vacuum.

I thought Max Jerman's paper on the current state of the art in CAI was excellent. If we were replanning the sequence of presentations then Bitzer, with emphasis on the future, should have followed Jerman to keep us chronologically oriented. The strands approach to curriculum programing described by Jerman is a very creative idea and helps to implement the general notion of individualized instruction. I commend that idea to those of you who are active in the field.

I am impressed with the conceptual variations in CAI utilization models. Jerman points out that Stanford's drill-and-practice material is constructed as supplemental education with the teacher presenting the fundamental development and expository material. That is a sort of a model with which they have done very well. In our Commonwealth CAI Consortium efforts, however, we have taken quite a different attack. We propose to put the basic developmental material on the computer in tutorial mode and to arrange for the teacher to enrich and supplement each pupil according to his needs from "off-line" materials. I think both approaches have merit and I hope other people will devise other utilization models or plans, for bringing CAI into the mainstream of the educational process.

I was impressed with what the speakers were not saying these past two days. For instance, I have heard very little discussion of the advantages of causing hard copy to emanate from the student station. A year or two ago almost every public discussion of CAI included a liberal dose of this kind of thing, and those of you who have been in it a long time will recognize it. I have not heard it spoken of here today or during these last few days. Maybe that indicates the speed with which this whole concept of CAI is moving.

Dr. Greenberg reminded us that a good strategy for the development of CAI as an education tool might be to avoid trying to make what he called full-blown courses as opposed to short instructional segments that could be woven through the instructional pattern. On the contrary, I believe that there is an important aspect of the evaluation of CAI which cannot be obtained until a large group of learners have had a long term exposure to CAI in significant aspects of the curriculum. Here, I think, we ought to have, at least someone ought to have, a four-year curriculum, let us say a four-year science and math curriculum, and they ought to expose the same group of learners to it over a four-year period. I think an evaluation of this kind of an experience with computer-assisted instruction is going to be a very important element in the eventual decision about its worth in American education. Of course, what we are doing now is short term. We put someone on for 15 minutes or an hour or three days or a term and we try to do some kind of an evaluation, but it will not tell us the answer to the big question about the importance of it until we get more long-term exposure for a particular group of students. Greenberg suggests renewed attention to the potential of the computer in diagnostic testing. This idea seems to me to be worth following up and incorporating into an experimental program for live learners.

That the student station should not be designed as a pale imitation of the human teacher was forcefully brought home to us by Dr. Kalin. Along this vein we need additional studies of the input and output rates of devices and the input and output rates of learners under different conditions. My guess is that data derived from memory drums, tachistoscopes, and films are no longer valid for complex CAI systems. If I may use Jerman's classification, the complex CAI systems, which I guess Glenn Bacon referred to as "bells and whistles" systems, are going to add an important dimension to CAI evaluation.

I found myself taking considerable exception to Dr. Zinn's remarks on programing languages, which I attribute to two causes. Differences in philosophy, perhaps, and the generation gap. (He's quite a bit younger than I am.) It seemed to me that Karl has weighed CAI in the balances against conventional instruction and has found CAI wanting. The fallacy in this is that he has conceived of conventional instruction, not in terms of the way it is, but rather the way it ought to be. On the other hand, he has put CAI on the scales in terms of the way it was two or three years ago rather than the way it is now, or the way it can be at the end of a reasonably rapid developmental period. Karl's major thesis is that CAI in author-controlled mode does not offer anything that cannot be done in a book or self-instructional text. I believe he would have a difficult time defending that statement after examining some of the sophisticated CRT-presented materials now on the line at The University of Texas, in Philadelphia, at Stoneybrook, or at Edmonton and other places. I will not yet claim that these fancy pyrotechnics advance learning, but I do not see how you could simulate them in a programed text.

The notion that students consider computers to be more believable than human beings in the role of teachers was a challenging idea brought out by Dr. Hansen. I agree that this tentative finding has serious implications for the implementation of CAI in the school. Our response in the Commonwealth CAI Consortium is going to be to try to get classroom teachers to identify with the computer program and to try to get pupils to realize that behind every computer program there is a responsible person. I commend to you in all earnestness the several generalizations about CAI curriculum development which Hansen has carefully distilled from his considerable experience at Florida State and Stanford. Almost everyone of them can be confirmed by our experience here at Penn State.

Dr. Bacon's interesting analysis of different roles and directions in the CAI community points up a kind of conflict, it seems to me, in future implementation. He says that volume is an important consideration in relationship to CAI—in order to make it cost-effective. Perhaps this is so, but it seems to me this is contrary to the obvious need for the slow growth and development of new knowledge about CAI teaching strategies. I guess what I am worrying about here is that we need time to develop knowledge about how to teach, how to present, how to sequence stimulus displays, how to get a computer to react to student responses, how to get a computer to evaluate what the student does over a long time span; but still we have to do that on the equipment that is going to be used in an operational education setting and we cannot get the operational education setting because of the high cost unless we can figure out ways to put it into half the classrooms of the country, or something like that. So it seems to me we are a little "hung up" here on the business of cost and need for new knowledge about teaching strategy. I hope somehow or other it will all come out in the wash and I am glad I do not have the responsibility for deciding how to do it.

Dr. Newsom's point about the responsibility of CAI course developers to be clear and patient in explaining their courses to curriculum design people who are responsible for overall curriculum is a very important point, and as I was reflecting on what he had said, I thought that one of the short term consequences of a lack of good CAI programs is the potential misuse of existing programs. There is the possibility that people are going to take a program because it exists, try to apply it in situations for which it was not designed, or give it to students or learners for whom it was not intended. So you need to be careful of your audience and try to fight against that kind of misuse. I hope this is just a short-term phenomenon that will soon be out of the way.

There is one point that was not brought up in this meeting, but I have seen evidences of it and so I thought, "Well, this is as good a place to mention it as any." I refer to the rise of charlatanism in CAI. It is a terrible thing that a new opportunity of the kind that we are facing has to be saddled with charlatans at such an early date. There is an organization now which, in its advertising, will make any teacher an expert in several author languages within a period of two weeks. If you send them a large sum of money, they will teach you all you need to know about CAI, and they will offer you a course for your staff in whatever depth you need. I think this is the forerunner of other "get-rich-quick" organizations. I do not know what to do about it, but I believe it is bad for the educational system and for the potential of CAI.

That educators have been and will continue to be slow in responding favorably to computer capabilities in education was pointed out by Dr. Newsom. This reminded me of the story of the little girl in the school cafeteria line. She came down the line and the supervisor saw her look at the spinach. She was asked, "Do you like spinach?" The little girl said, "Yes." So she was given some spinach and then as she was about to go out the supervisor noticed that the spinach was still on her plate. She said, "But you told me you liked the spinach." And the little girl replied, "Well, I like spinach all right, but I don't like it well enough to eat it!"

I am sure I express for Dr. Rackley and President Walker and for your official hosts our pleasure in your participation here. We have all been enriched because I am sure each of you has left a little bit of yourself at Penn State. Thank you very much!

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